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"HONOR" ENGINEERING STUDENTS: THEIR CHARACTERISTICS AND REASONS FOR SUCCESS[1]

BY M. E. HERRIOTT

Bureau of Educational Research, University of Illinois

The faculties of colleges of engineering have no doubt given as much or more attention to studying their student personnel than have the faculties of any other college or professional school. We may especially note the investigations of the Society for the Promotion of Engineering Education. The "honor" system at the University of Illinois offers an opportunity for the study of students who have been particularly successful. "Honors" are conferred upon those "students in the upper 10 per cent of each class"—freshman, sophomore, junior and senior—who are thus given "public official recognition" because of having attained a "high grade of scholarship." In order to take advantage of this opportunity, some of the more significant characteristics of a group of "honor" students registered in the College of Engineering during the first semester of the school year 1926–27 were ascertained in the following manner. Two group conferences were held, attended by twenty-five and twenty-three students, respectively. *The Otis Self-Administering Test of Mental Ability, Higher Examination, Form A,* was given. The students provided data relative to chronological age, time devoted to study, and use of extra school time. They also answered a study-habits questionnaire of forty-eight items. At a personal interview of approximately twenty-five minutes, the study-habits questionnaire was briefly discussed in order to clear up points about which there was any misunderstanding. In the main, however, the interview was devoted to an inquiry as to why

[1] The writer wishes to acknowledge his indebtedness to Professor Walter S. Monroe, Director of the Bureau of Educational Research, and Dean Milo S. Ketchum and Assistant Dean H. H. Jordan of the College of Engineering, University of Illinois, for their advice and cooperation.

these students thought they succeeded. Immediately following the interview, the investigator had the temerity to attempt to rate each student on certain personality traits in so far as it was possible to observe them during the interview and preceding group conference. Scholastic records and disciplinary data were secured from the registrar's records.

The remainder of this article is devoted to a report of the results obtained by means of the procedure thus briefly outlined. In addition, comparisons are drawn wherever possible between the results of this study and a study by Q. C. Ayres of a more representative group of engineering students at the Iowa State College of Agriculture and Mechanics Arts.[2]

Scholastically, these students all had better than a "B" average[3] for the one or two semesters on the basis of which they were selected as "honor" students.[4] All but three of them had an average better than "B" for all of their university work up to the time of the investigation—periods of three, five, and seven semesters for the sophomores, juniors, and seniors, respectively. The three who fell below a "B" average were sophomores who did not maintain the standing they had attained during their first semester.

The *chronological ages* of these students may be best considered on a graduation basis. Assuming that all would graduate at the normal time, six months, one year and six months, and two years and six months were added to the given ages of the seniors, juniors, and sophomores, respectively. The median graduation age is thus twenty-two years, with a range from twenty-one to twenty-seven years. Comparison may be made

[2] Ayres, Q. C. "A Study of Engineering Education at Iowa State College as Based on Facts and Opinions of Students and Alumni," *Iowa State College of Agriculture and Mechanic Arts Official Publication,* Vol. 26, No. 30, Bulletin 86. Ames: Iowa State College, 1927. 80 p.

[3] The marking system is A, B, C, D, E.

[4] The sophomores in this study were freshmen at the time they were designated as "honor" students. Freshmen are selected on the basis of their first semester in school. All other students are selected on the basis of their records for the two semesters preceding honor's day, which were, for the group studied, the second semester of 1924–25 and the first semester of 1925–26.

between these facts relative to this group and age-at-graduation data provided by Cleland[5] for 4,000 men and whose names appeared in "Who's Who in America" and an unselected group (number not given) of college graduates. Table I presents these data in form of comparison. It

TABLE I

AGE AT GRADUATION OF THREE GROUPS OF STUDENTS[6]

Age at Graduation	Per Cent of Unselected Graduates	Per Cent of 48 "Honor" Engineers	Per Cent of 4,000 Who's Who
18	0.50	0.00	1.44
19	0.87	0.00	5.60
20	8.66	0.00	11.90
21	15.76	22.92	19.00
22	21.93	41.67	21.20
23	18.47	14.58	14.70
24	15.37	10.42	8.70
25	10.17	6.25	6.30
26	3.27	2.08	4.10
27	0.00	2.08	0.00
	95.00	100.00	92.94

appears from the figures that the "honor" students did not differ markedly in age from either "average" students or those who distinguished themselves later, except for a noticeable absence of the very young, higher per cents in the twenty-one and twenty-two year groups, and a slight tendency toward over-ageness. Tentatively, it appears that a certain degree of maturity is, at least in a professional school, a concomitant of marked success in college work.

In *intelligence*, as measured by the Otis test, all of these "honor" students, except a Chinese boy with a language handi-

[5] Cleland, J. S. "Age at Graduation and Success in Life," *School and Society*, 21:31–32, January 3, 1925.

[6] This table should be read as follows:

Of students in general, 0.5 per cent graduated at eighteen years of age; of forty-eight "honor" engineers, none will graduate at this age; and of 4,000 "Who's Who," 1.44 per cent graduated at this age. The remainder of the table should be read in similar manner.

cap, rated above the average of college students in general, although a few approached the median for college students. This median is 41, and the lowest score made by an "honor" student is 42. Table II presents comparative data for the 47 English-speaking students and 2,516 college students. Examination of this table shows that all of these "honor" students made scores better than the median for college students in general, that approximately 55 per cent of them were equal to or better than the upper 10 per cent, and 21 per cent

TABLE II

COMPARISON OF INTELLIGENCE SCORES OF "HONOR" STUDENTS WITH OTHERS ON THE OTIS SELF-ADMINISTERING TEST OF MENTAL ABILITY, HIGHER EXAMINATION [7]

Point Scores	Per Cent Equaling or Exceeding 2516 College Students [8]	47 "Honor" Students [9]
16	100.0	100.0
25	97.0	100.0
30	90.0	100.0
36	75.0	100.0
41	50.0	100.0
49	25.0	80.9
55	10.0	55.3
61	3.0	21.3
75	0.0[10]	0.0

equaled or exceeded the upper 3 per cent of college students taken at random. These facts are, of course, indicative that high intelligence, as measured by the conventional intelligence test, is a concomitant of high scholastic achieve-

[7] This table should be read as follows: Of 2,516 college students who have taken the Otis Self-Administering Test of Mental Ability, Higher Examination, 100 per cent made a score of 16 or better; of 47 "honor" students, 100 per cent also made a score of 16 or better. Dropping farther down the table, of the 2,516 students, 25 per cent made a score of 49 or better; of the 47 students, 80.9 per cent made a score of 49 or better. The remainder of the table should be read in similar manner.

[8] The data for 2,516 college students were taken from the manual that accompanies the Otis test.

[9] The one foreign student with a language handicap was excluded from these calculations.

[10] Only one college student has been reported who, with a twenty-minute time limit, has made a perfect score of 75.

ment. However, making due allowance for imperfections in the test and testing conditions, it appears that the relationship is not an exact one, for if it were, practically 100 per cent of this group would equal or exceed the upper 10 per cent of a random sampling of college students. That 55 per cent of them did is significant, but that 45 per cent of them did not is also significant.

As to *study habits*, the answers to the questionnaire indicate that the study practices of these students were in relatively close agreement with those advocated by such authorities as Whipple[11] and Kornhauser.[12] However, the data were secured in such form as not to be readily compared with the results of other investigations, such as those reported by Jessie Allen Charters[13] or Luella Cole Pressey.[14] Inasmuch as comparisons are not feasible, the next best thing is to present the study practices observed by most of this group of students. The following are twenty-six of the study practices that most of these students regularly followed. These are stated in the form of admonitions. In the questionnaire they were stated as questions.

1. Systematically review the textbook before final examinations.
2. Explain problems and processes for other students when there is an opportunity to do so.
3. Systematically review the textbook before quizzes.
4. Ask either in class or in conference about items needing explanation.
5. Write up chemistry experiments in the laboratory with the experiment still set up.

[11] Whipple, Guy Montrose, "How to Study Effectively" (Second Edition Revised and Enlarged). Bloomington, Illinois: Public School Publishing Company, 1927. 96 pp.

[12] Kornhauser, Arthur W., "How to Study—Some Suggestions for Students." Chicago: University of Chicago Press, 1924. 43 pp.

[13] Charters, Jessie Allen, "Methods of Study Used by College Women," *Journal of Educational Research*, 10: 344–55, December, 1924.

[14] Pressey, Luella Cole, "What Are the Crucial Differences Between Good and Poor Students?" Chapter I in: Pressey, Sidney L., *et al.*, "Research Adventures in University Teaching." Bloomington, Illinois: Public School Publishing Company, 1927. 152 pp.

6. Memorize rules and formulae only after thoroughly understanding them.
7. If you do not understand how to proceed in solving a problem after reading it, try to reason out the procedure or look up the solution to similar problems, preferably the former.
8. When doing an experiment, read through and try to understand all of the directions before beginning work; do not merely read the directions as the experiment progresses.
9. Read over an assignment rapidly to get a general idea of the author's treatment and then study in detail.
10. Recite your lesson occasionally to yourself, either aloud or in a whisper.
11. Do not confuse that which is not assigned with that which is.
12. Systematically review your textbook when you need facts previously learned if you do not recall them.
13. Understand exactly what is given and what is to be done before you begin to solve a problem.
14. Read your textbook relative to the subject of a laboratory experiment before doing the experiment.
15. Try to determine the reason for statements made by an author.
16. Try to connect important points with something in your own experience.
17. Apply rules and formulae soon after learning them rather than trust that you will remember them without doing this.
18. In case the answer to a problem is not given by the instructor or textbook, solve it before trying to ascertain the correct answer from your classmates or those who have previously taken the course.
19. If a problem is made up of a series of steps, be careful to separate it into the several steps.
20. Frequently supplement what a lecturer says by supplying examples of your own, thinking of what someone else has said along the same line, and the like.
21. Be sure that you clearly understand what your instructor asks you to do in his assignments.
22. Divide your study of an assignment into two periods.
23. Do each assignment with dispatch, but complete all work.
24. When possible, check your answers to problems.
25. Check each operation as performed, rather than leave all checking until the entire problem is completed.
26. Be sure to find out the meaning of unfamiliar terms.

It is also of interest to note the study practices that are often advocated by authorities but which few of these students ever followed. These were:

1. Follow a fairly definite study schedule.
2. As you read, keep notes in some systematic way, such as in a notebook.
3. After studying an assignment, write out a summary or outline of the material read.
4. Systematically review your textbook daily.

As to *time spent in study*, these students' estimates ranged from zero to five hours per class meeting. Exclusive of the lecture meetings of certain courses, the median estimated time spent in preparation per class meeting was an hour and a half. However, if all class meetings are included, the median becomes one hour of preparation for each hour spent in lecture, discussion, or laboratory. This is approximately the same amount of time that other investigators find that students in general spend in study.[15]

As to *personality*, it was the opinion of the investigator, after trying to rate these students, that they ranked well above the average of college students. Cooperativeness and initiative seemed to be the two most prominent personality traits.

In their use of *extra-school time*, twenty-six of the forty-eight students engaged in remunerative employment or home work [16] during their freshman year, and eleven of the twenty-one juniors and seniors were thus employed during their sophomore year. One student worked more than forty-five hours a week and earned $470.00 during the school year. Only one of the eleven juniors and seniors worked less than a hundred hours during his sophomore year. In connection with

[15] *See* Comstock, A. "Time and the College Girl," *School and Society*, 2:326–27, March 14, 1925; Goldsmith, Alfred G. and Crawford, C. C., "How College Students Spend Their Time," *School and Society*, 27: 399–402, March 31, 1928; Hutchinson, R. G. and Connard, M. H. "What's in a College Week?" *School and Society*, 24: 768–72, December 18, 1926.

[16] Home work was the equivalent of remunerative employment, except that the students were not paid directly for it. For example, one boy handled a milk route for his father.

these data relative to remunerative employment and home work, it is interesting to make some comparisons with the results of Ayres' study.[17] He found that only 15 per cent of the students were financed entirely by their parents, and that of the freshmen, over 40 per cent earned more than half of their expenses. It appears that in this respect there is very little difference between "honor" students and students in general.

TABLE III

AMOUNT OF LEISURE-TIME READING DONE BY "HONOR" STUDENTS[18]

No.	Books		No.	Magazines		Newspapers	
	Fresh. Year (47 Students)	Soph. Year (26 Students)[19]		Fresh. Year (46 Students)	Soph. Year (28 Students)[19]	Fresh. Year (47 Students)	Soph. Year (29 Students)[19]
None.....	5	9	None	17	9	3	2
1–5.....	24	6	1	6	0	17	7
6–10.....	10	4	2	11	9	16	11
More than 10	8	7	3	5	5	10	9
			4	1	1	0	0
			5	2	1	0	0
			More than 5	4	3	1	0

Table III gives some indication as to the extent to which these students employed their extra-school time for leisure reading. The questions asked relatively to their reading habits were: "Other than those directly connected with your class work, how many books did you read during the school year?" and "How many magazines and newspapers did you read regu-

[17] *Op. cit.*, pp. 15 and 24–25.

[18] This table should be read as follows: Of the 47 students reporting for their freshman year, 5 read no books other than those directly connected with their class work; of 26 students reporting, 9 read no books during their sophomore year; of 46 students reporting, 17 read no magazines regularly during their freshman year. The remainder of the table should be read in similar manner.

[19] It should be noted that most of the sophomores did not reply to these questions for the sophomore year, although some thought that they knew their habits well enough to do so.

larly; i.e., every, or nearly every, issue?" From the data presented in Table III, it appears that these "honor" students are rather prolific readers. Comparison can be made with the results of Ayres' study.[20] He found that 50 per cent of his group of students reported reading five to seven newspaper issues a week, 16 per cent more than seven issues. In the case of these "honor" students, in both their freshman and sophomore years, more than 90 per cent read one or more newspapers regularly. In addition to this, they did considerable magazine and book reading. Data that would make possible comparisons of the amount of voluntary reading of technical literature were not obtained.

As to *discipline,* it is worthy to note that not one of these "honor" students had a single mention of university discipline entered on his record in the registrar's office.

As to *why these students thought they succeeded,* the following information is of considerable interest. Before presenting their reasons, it is best to tell briefly the way in which the personal interview was conducted. The principal question considered was, "Why do you think you have succeeded?" This question was amplified and talked about, notes being made as significant points were brought out. Every effort was made to put the students at ease and also to make them feel that they were contributing to a worth-while investigation. Sometime during the interview, the question was turned around and made less personal by being stated, "Why do you thing students fail, or have difficulty in making passing grades?" This served to put a different angle on the matter and usually brought out points not thought of previously. Almost invariably a student regarded as causes of failure characteristics diametrically opposed to those that he conceived to be reasons for his own success. It should be emphasized that the investigator did not approach the interview with any preconceived notions about reasons for success which he imposed upon the students. In fact, he conscientiously limited himself to asking, clarifying, and amplifying the question. Table IV makes

[20] *Op. cit.,* pp. 12 and 24.

it apparent that without any suggestions before them, most students thought of only a few reasons for success (seldom more than three and usually only one); whereas, with a list of suggestions, each student found that several applied to him.

After twenty-five students had been interviewed, their reasons for success were listed. This list of twenty-two reasons, with one added by the investigator, was presented to each of the remaining twenty-three students after the interview had proceeded as just outlined. Each student was instructed to indicate those reasons that he considered potent in producing his own success and those that he felt had no bearing on his success. In addition, since each student evinced a desire to indicate the two or three reasons that he thought were especially important, these also were marked.

Table IV presents a tabulation of the results. This table is of interest, first, because it contains the reasons that a group of markedly successful students in a professional school assign for their scholastic success; second, because of the character of these reasons. Two types of reasons are outstanding: (a) study habits, and (b) attitudes toward school work. Furthermore, certain generally recognized malpractices, such as cramming, are given small significance as compared with accepted good practices, such as purposing to get the content of courses and allowing grades to come as a natural consequence.

Here again some interesting and valuable comparisons can be made between this study and the one by Ayres.[21] It will be noticed that in the case of these "honor" students, interest in engineering subjects was considered to be one of the most important reasons for their success. In the case of those studied by Ayres, a number of the deciding influences to go to college and study engineering which were listed are of a closely related nature, such as: "liking for science," "liking for apparatus," "professional appeal," and "liking for construction." It would be interesting, and perhaps important, to know how the various influences listed by Ayres would be distributed among students of varying degrees of success.

[21] *Op. cit.*, pp. 13 and 26–27; pp. 14 and 27–28; pp. 17 and 29.

	Reason	Mention By First 25		Rating by 23 Other Students					
				Potent		Especially Important		Lacking	
		f	r	f	r	f	r	f	r
1.	Interest in engineering and engineering subjects	10	1.5	21	1	3	10	0	2.5
2.	Regularity of class attendance—few or no cuts	2	12	20	3	5	5	2	10.5
3.	Concentrated effort when studying	7	5	20	3	6	3	0	2.5
4.	Close attention to what is done in class	2	12	20	3	4	7.5	0	2.5
5.	Punctuality in handing in work	5	7.5	19	5	2	13	1	6.5
6.	Good study conditions, including physical conditions, influence of roommates, general atmosphere, and the like	8	3.5	18	6.5	5	5	2	10.5
7.	Purposing to get content of courses—grades will come	1	19	18	6.5	1	17.5	0	2.5
8.	Regularity of daily preparation, including persistent effort and "hard work"	10	1.5	17	8.5	8	1	1	6.5
9.	Thoroughness in all work	5	7.5	17	8.5	4	7.5	2	10.5
10.	"Mastery" of the first part of each course	1	19	16	10	3	10	1	6.5
11.	Native ability, *i.e.*, intelligence			14	11	7	2	2	10.5
12.	Proper evaluation of different phases of courses, giving greater attention and emphasis to the important phases	2	12	12	12	3	10	1	6.5
13.	Anticipation of what will be asked on quizzes	1	19	11	13	2	13	3	13.5
14.	School work and success in it valued above other phases of college life	2	12	9	15	1	17.5	3	13.5
15.	Practical experience closely related to the work in the College of Engineering	6	6	9	15	2	13	8	17.5
16.	Always easy to get school work	1	19	9	15	5	5	8	17.5
17.	Maturity	1	19	8	17	0	22	9	20
18.	Purposing to get high grades	2	12	6	18.5	1	17.5	7	15
19.	High-school work had much in common with the work in the College of Engineering	8	3.5	6	18.5	1	17.5	8	17.5
20.	Successful cramming	2	12	5	20	0	22	12	23
21.	Necessity—cannot afford not to get high grades	1	19	4	21	1	17.5	8	17.5
22.	Study lessons at first opportunity after being assigned	1	19	3	22.5	1	17.5	10	21
23.	Keep ahead of the class in so far as possible	2	12	3	22.5	0	22	11	22

[22] This table should be read as follows: "Interest in engineering and engineering subjects" was mentioned by ten of the first twenty-five "honor" students as a major factor of their scholastic success; twenty-one of the twenty-three students in the second group checked it as a potent factor; three checked it as especially important; and none checked it as lacking. This factor had a rank in each of the four lists of 1.5, 1, 10, and 2.5, respectively. The remainder of the table should be read in similar manner.

Attention should be called to the fact that the ranking of items in each of the four respects is on the basis of frequency of mention with reference to significance as factors of scholastic success. Thus, the greater the frequency of mention, the higher the rank in the first three columns; but in the fourth or "lacking" column, the ranks and frequencies bear a reversed relation to each other.

It was the impression of the writer that "honor" students stood out markedly in their liking for engineering subjects as distinguished from merely liking to go to school or to study.

It is very interesting to note that in the opinion of these students, study habits rank high among reasons for success. The enumeration earlier in this paper of the study habits these students laid claim to is evidence that their practice was in fair agreement with what authority says it should be. Ayres noted that the most significant trend divulged in replies to one of his questions relative to weak elements in preparation for college was the realization among students that they never learned how to study properly and efficiently. He also discovered that more than 63 per cent of his students checked "inability to study" as one of their difficulties in college. This was by far the most outstanding difficulty noted by these students.

Although data are not presented herewith, it is interesting to note that the present study confirms Ayres' observation that, among engineering students, English heads the list of "least interesting courses" in college.

To *summarize*, these "honor" engineers, with the exception of three sophomores, maintained a scholastic average of better than "B" up to the time data were collected. In chronological age, they did not differ markedly from college students in general nor from those who later distinguished themselves, except that there was a noticeable absence of the very young and a tendency toward over-ageness. In intelligence, all of them (except the student with the language handicap) made scores better than the median college student, and more than 50 per cent of them equaled or exceeded the upper 10 per cent of college students in general. Their study habits were in fairly close agreement with those advocated by authorities. They spent an average of an hour and a half in preparation per class meeting for classes demanding such study. In personality, they appeared to be superior to the average college student. About half of them engaged in remunerative employment or home work to the extent of a hundred hours or

more during the school year. They appeared to be rather prolific readers. None of them had ever been involved in disciplinary difficulties while in the university. The most outstanding reasons assigned by them for their success may be classified either as good study habits or proper attitudes toward school work.

REPORT OF CONFERENCE ON MECHANICS, JUNE, 1928

THE EMBRYO TEACHER OF MECHANICS

E. W. RETTGER

Cornell University

As a member of the instructing staff at the Cornell session of the Conference on Mechanics in 1927, I had the opportunity to question a number of those present. I was particularly interested in the difficulties they met when they began to teach mechanics. Their replies to my questions were so in accord with what I felt was the case, that since last summer I decided to extend my inquiry. Accordingly, I took every opportunity to question teachers of Engineering. I should like to have made my inquiry general by sending out a questionnaire, but this was out of the question. As a result of this inquiry, I am of the opinion that the following statements may be taken as essentially correct so far as instructors of mechanics are concerned.

1. While students, very few of our present instructors ever thought of becoming teachers of engineering and by far the most of them would have ridiculed the idea of ever teaching mechanics.

2. When they graduated, very few indeed thought that they were now going out to get some practical experience that might be of assistance to them later as teachers of mechanics.

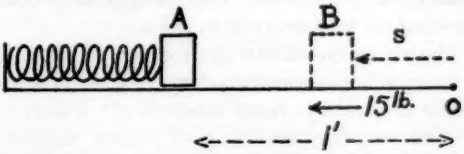
3. Many of the instructors began to teach not with the idea that teaching was to be their profession, but rather with the idea that after a year or so they would go back to practical work. To them, teaching was a makeshift or a temporary inconvenience. For instance, business was dull and they decided to teach for a year or so until business picked up again. The opportunity to do advanced work, and the desire to be at home for two or three years, were other reasons given. Of those who expected to make teaching their profession, some did not like practical work and decided that teaching was

the lesser of two evils, while some thought they would like to teach. It is significant to add that of all the instructors questioned, very few began to teach mechanics because mechanics was their preference. They taught mechanics simply because mechanics was assigned to them.

Now if the above statements are correct, and I believe they are, then the question naturally arises: *Are the new instructors of mechanics prepared to teach mechanics?* I have no hesitation in saying that they are *not*. Of course, there are exceptions. I have known persons who made excellent instructors right from the start. We are not concerned, however, with the exceptions, nor are we concerned with the status of the instructor after two or three years of experience when he begins to find himself and not infrequently makes an excellent instructor. We are concerned with the beginner, the embryo teacher of mechanics, and I will repeat that he is not prepared as a rule to teach mechanics. His knowledge of *mathematics* is limited to that learned in the required elementary courses, much of which he never clearly understood or has forgotten. He has made no systematic study of *mechanics* beyond the required course and much of that he either never understood or has forgotten. He has made no study of methods of teaching mechanics and often is at sea when he begins to teach mechanics. Moreover, too frequently he has no desire to make the teaching of mechanics his profession.

I fail to see how any one can teach mechanics unless he has a clear understanding of mathematics—calculus, for instance. True, he may eliminate the mathematics and reduce mechanics to the blind use of rules and formulas, but is this desirable? I do not think so. Unless I am mistaken, this is just what is done far too frequently. The derivation of the theorems of geometry is recognized as essential in the study of geometry. Why should not the derivation of the theorems of mechanics be essential in the study of mechanics? It would be, if instructor and students understood the mathematics. I believe I am right in saying that the instructor in mechanics is apt to be woefully deficient in his knowledge of mathematics. Not long ago I received a letter from an instructor in me-

chanics. He inclosed the solution of a problem and he wanted to know why the velocity should turn out to be negative. Here is the problem as he gave it:



A spring whose constant is $k = 1{,}000$ (ft. lb. sec.) is contracted 1′ as shown in the figure. A body weighing 64.4 lb. is placed in front of the spring and the spring is released. Assuming that the body starts from rest at A and that a constant friction of 15 lb. is acting on the body, it is required to find the velocity of the body at O. Use the principle of work and energy.

Here is the solution as he gave it:

$$\int_1^0 1{,}000\, sds = 15 \times 1 + \frac{1}{2} \times \frac{64.4}{32.2} V^2 - O$$

or $$-500 = 15 + V^2$$

or $$V^2 = -515;$$

$$\therefore V = -\sqrt{515} = -22.7'/\text{sec}.$$

Why should the velocity be negative?

I had to write him that he had made two errors in the solution of the problem, one in calculus and one in algebra. As the body moves from A to O, s is decreasing. Now the differential of a decreasing function is negative. Hence the increment of displacement is negative $(-ds)$. The solution of the problem then is as follows:

$$\int_1^0 1{,}000\, s(-ds) = 15 \times 1 + \frac{1}{2} \times \frac{64.4}{32.2} V^2 - O,$$

$$500 = 15 + V^2,$$

$$V^2 = 485,$$

$$V = 22.02'/\text{sec}.$$

The mistake he made in algebra is of course obvious. If $V^2 = -515$, then V does not equal $-\sqrt{515}$ but $\sqrt{-515}$. That is, the velocity would be imaginary and therefore physically would not be possible.

I stated in my letter that great care must be used not to violate the laws of mathematics, and I gave him the following illustration showing how absurd results may be obtained if the laws of mathematics are not strictly followed:

Let $$x = -3/2.$$

Then $$2x + 3 = 0.$$

$$x^2 + 2x + 1 = x^2 + 2x + 1 \quad \text{(identity)}$$

Adding,

$$x^2 + 4x + 4 = x^2 + 2x + 1$$

or $$(x + 2)^2 = (x + 1)^2$$

or $$x + 2 = x + 1$$

or, cancelling x, $$2 = 1.$$

In reply to my letter he stated that he had carefully examined my illustration and that he could find nothing wrong with the mathematics, but that the results certainly were absurd. He concluded his letter by saying that higher mathematics was unintelligible, and therefore should be eliminated.

I quite agree with him that higher mathematics should be eliminated from elementary mechanics. I fail to see, however, how by any stretch of the imagination any of the above mathematics can be classified as higher mathematics.

Whether we like it or not, the fact nevertheless remains that mechanics is a mathematical subject. Now, mathematics is a language. To express yourself correctly in any language, the laws and rules of that language must be followed. If you do not do so, you may say something entirely different from that you intended to say. To the speaker's own great embarrassment he discovered that there is a Spanish word which when properly written is a very good and proper word to use,

but forget to put a mark over the letter "n" in that word, and it becomes a word not used in polite society. The average instructor's knowledge of mathematics is just about on a par with my knowledge of Spanish, and the mistakes he makes in the use of his mathematics are apt to be just about as ridiculous as the mistake I made in attempting to use Spanish.

If I read the signs of the times correctly, there is a general tendency to reduce engineering to a more scientific basis. We may not like this but we cannot help ourselves. Formerly, engineering practice was largely the result of experience. What did it matter if a beam was larger than necessary? With the increase in the cost of the material, with the demand for higher unit stresses, with the present development of larger units, higher speeds and so on, a more exact knowledge of the distribution of the stresses is imperative. This means a more rigorous mathematical analysis. Not only that but in other branches we find the same tendency. In certain branches of chemistry, biology, economics, etc., a knowledge of calculus is necessary. In my opinion this demand for a better understanding of the calculus is going to increase. How discouraging this would be if it were true that mathematics is unintelligible! That mathematics is unintelligible to a great many engineers, even to teachers of mechanics, is a fact that no one can deny; but need it be unintelligible? I do not think so. By means of a graph here, a concrete illustration there, the fundamental ideas of the calculus can be brought out and the calculus can be made intelligible.

Now what can be done that will materially help to remove the difficulties of the embryo teacher of mechanics? Evidently, a three-weeks' conference on mechanics such as was held last summer, even assuming that such a conference were held every summer, would not be a solution of the problem for several reasons, one of which is this: The men who would attend such a conference are those who have had one or more years of experience and who have found out that there are difficulties. We are concerned now with the embryo teacher, and he, as a rule, has no idea of the difficulties he will meet as a teacher of mechanics. If it were possible to require of every

person who expects to teach mechanics that he spend at least one year in graduate work, the problem would be much simplified. Even assuming, however, that it were possible to induce men to take graduate work as a preparation for teaching, at what university in this country would there be a sufficient number of graduate students who expect to teach mechanics to justify giving a well organized course with special reference to the needs of the teacher of mechanics?

We all like to dream dreams and build air castles. I am certainly guilty of that. Of the air castles that I build there is one, impracticable to be sure, nevertheless pleasant to build. That is, in my dreams, I sometimes build a Graduate School for the Training of Engineering Teachers. I see it located at some leading university; not always at the same university, now here now there, but in no sense a part of that university. It is under the control of the Society for the Promotion of Engineering Education and its staff is selected from the educational field at large. The students come from all parts of the country and the courses are well organized and coordinated, and designed especially for the needs of the teacher. That means that methods of teaching are kept in mind continually on the theory that the best way to learn to teach is by actually observing some one who can teach. At the end of a successful and profitable year of study, I see these men leaving to take up their duties as instructors in the different universities in this country. These are pleasant dreams, but we might as well wake up and face the facts. What are the facts? A class in mechanics is to be put in charge of a man who is not prepared to teach mechanics and who has had no experience as a teacher. What can we do to help him over his difficulties?

Until recently, I had charge of the Summer School Mechanics at Cornell. Every summer, the selection of the staff and the arrangement of the work was left to me. No matter how careful we were in planning and preparing for the Summer School Mechanics almost invariably we were in want of an instructor or two at the last moment and sometimes there

was no one of the regular staff of the Department of Mechanics available. Several times we had to take some instructor from some other department. He had had experience as a teacher, but he never had taught mechanics. This did not prove to be satisfactory to say the least, and a great deal of complaint was heard from the students. Later on, I hit on a plan that solved the problem to a large extent. This plan I am going to explain, believing that it is a plan worth considering.

Let A be an experienced and successful instructor, and let B be the new instructor who is now to teach mechanics for the first time. Arrange the work in such a way that B's class tomorrow will have the same lesson that A's class has today; that is, B's class will always be one day behind that of A's class. Arrange the work in such a way that B can enter A's class just as if he were a regular student. He need not take part, of course, in A's classroom discussion, but he should note the difficulties the students have and how the instructor meets them. He should also note A's method of procedure. Now select a convenient time during that day for B to consult A concerning the lesson of that day. During this consultation A can explain to B any difficulties B may have, and can make suggestions that may help B to teach that same lesson tomorrow. This consultation may take five minutes or it may take half an hour. Now let B prepare himself to teach that same lesson tomorrow to his own classes. If this plan is carried out properly, many of the difficulties of the new instructor will be removed, and he is much more likely to be a success the first year he teaches.

To make this plan a success, several conditions must be met:

(1) Lesson assignments must be made out several days in advance so that B may know several days ahead just what lesson A will assign on a certain day. This in itself helps to eliminate many of B's difficulties. What lesson to assign, how long to make that lesson, and what problems to assign often are sources of a great deal of B's difficulties.

(2) B must not be overloaded. An instructor told me re-

cently that when he started out to teach he was given one class in mechanics, one in hydraulics, one in surveying, and a laboratory course in another subject. This is cruelty to the instructor. How can anyone be expected to do good work under such conditions? The new instructor should have a light schedule and certainly should not be expected to teach three or more subjects, especially when one of those subjects is mechanics.

The plan I would like to suggest then is as follows:

1. Give the New Instructor a lesson schedule for his course. This lesson schedule should go into considerable detail. If you like, let this lesson schedule be that of an experienced and successful teacher.
2. Let the New Instructor's schedule be one day behind that of the old instructor's schedule.
3. Let the New Instructor visit the old instructor's class each day, and give ample opportunity on that day for consultation between the two instructors.
4. Now, let the New Instructor make the necessary preparation to teach that same lesson to his class on the next day.
5. Give the New Instructor a light schedule.

I am making a plea for the Embryo Teacher of Mechanics. He deserves greater consideration than is usually given him. Start him going in the right direction and perhaps he will continue going in the right direction of his own accord. The plan suggested may not be the best plan. It is quite possible that some of you may have better plans. If so, we should like to hear what they are.

A COMPARISON OF CLASSROOM METHODS IN THE TEACHING OF MECHANICS

A. P. POORMAN
Purdue University

Each possible method of instruction in the classroom has certain advantages and likewise each has its limitations. The method which works well one day does not always prove

equally desirable the next. The lesson, the weather, the attitude of the class, outside noises or visible distractions may make advisable a change of method. The true and experienced teacher is of course an artist in his profession and senses intuitively the situation in his classroom which demands one procedure and that which calls for another, but the beginner and the man to whom teaching comes hard may welcome some suggestions intended to be helpful.

When taking up a new principle or a new part of the subject, the lecture method has decided advantages. The instructor should not depend upon spontaneous inspiration, but should prepare carefully his mental list of headings and subheadings in the proper order for clarity and emphasis. A written list may sometimes be necessary, but a break in continuity is always sensed by the class if a trip from the blackboard over to the desk is necessary before starting on the next subheading. The textbook should seldom be referred to by the instructor. If he is lost without his text open before him, he has not made proper preparation. He owes it to his students, to himself and to his profession to master the day's assignment thoroughly enough to be independent of the text, and to feel confidence in his ability to handle any of the applications of the principle. Questions by the class, either relevant or irrelevant should not throw the instructor off his stride. Such questions should always be answered courteously and, if relevant, as fully as possible considering the limitations of the class period. If the question is irrelevant, the instructor should insist gently but firmly that it is necessary to go on with the regular lesson. If any tendency to somnolence among the students is noticed and if the ventilation is proper, it may be necessary to change the procedure and begin an oral quiz or invite class discussion. Then when attention is obtained again, the lecture may be continued. Noisy machinery, nearby building operations, the campus switch engine or a regimental parade may interfere with a lecture to such an extent as to make it advisable to substitute blackboard or paper work.

The instructor should beware of overdoing the lecture method, of using it when one of the other methods would be better. If the instructor is a fluent talker, it is the easiest one, especially for the instructor, and the students will rarely object to it. The lecture method affords no basis for obtaining a grade for the student, unless a grade be given for attention, which in many cases would be manifestly unfair.

After a new principle has been developed, the class discussion method has been found very useful and very economical of time. If questions are forthcoming from the class, they are answered either directly or by the indirect method of asking other questions which bring out the underlying principles and induce the student to work up to the final result step by step in order. If no questions are asked, the instructor should have some of his own, and should be able to get a good lively discussion started. Following the discussion on the theory, the application of the principle to the solution of problems is usually next in order. In general, the instructor should do the work at the blackboard—always in such a position on the board that all of the class can see—but the students, first one, then another, should be called upon to help in the solution, in such things as specifying the free body, naming the forces that are known, suggesting the method of attack, giving numerical results with the slide rule or from tables. Occasionally some student may be asked to go to the board and do the work, but this usually slows down the solution considerably. This class discussion helps to fix in the student's mind the relation between the basic principle and the engineering problems to which it applies. There is a disadvantage to this method in the fact that it may waste the time of some of the students who may have mastered already the problem being solved. The instructor soon learns to know these students, however, and should use them judiciously in helping in the solution. They should also be encouraged to do more than the bare minimum, and their mettle should be tried occasionally by giving them a chance to show what they can do on a more difficult or more advanced problem. There is also

some disadvantage to this method if used regularly in that many students will do little work in preparation and will expect the instructor to feed him the lesson in predigested bits. If the student can master the subject by this method, it becomes for him a great time-saver, but some try it whose wits are a little too slow, with the result of final failure in the course. If desired, grades can be given upon answers elicited during such class discussion, but on account of the fractional nature of the questions and the difficulty of weighting properly the different questions necessary to be propounded during such discussion, this is hardly fair to the student. The class discussion will be more easy and informal if the students know that no grades will be given on their answers to such questions. The student will also be more inclined to ask questions of his own, and such questions are of great value to the instructor in enabling him to see the student's approach to the problem and the difficulties he encounters.

The oral quiz or recitation method, used so freely in the public schools and to some extent in college, has the advantage of forcing the student to think on his feet and to keep awake to what is going on in the class. If the questions used are carefully prepared by the instructor, such recitations may be used for a fairly accurate grading of the student's work, even though the questions can not be made of equal weight. To obtain the proper instructional benefit for the class, incorrect answers should always be corrected, either by the instructor or by another student. In some cases, the correct answer is suggested by the incorrect answer given previously, so the real amount of credit deserved by the second student is often uncertain. No permanent record of the student's answer persists, so that if the instructor's estimate is ever questioned, there is no evidence which may be examined. If the instructor keeps his grade book in his hand and marks down a grade as each student recites, the atmosphere is more that of a court of justice than of a classroom. If the grading is deferred until after class, a proper appraisal of each stu-

dent's answer is quite difficult, especially if the number in the class exceeds twelve or fifteen. For real instruction in a subject as difficult as mechanics, this method of classroom procedure has rather small value. It gauges the student's home performance, but does not open up new paths of knowledge.

If space is available and classes are small, say not exceeding fifteen, work at the blackboard may be made very valuable. The problems assigned should of course be carefully prepared, and in general should be slightly different from those in the lesson. Each student is busy, erasure of mistakes is easy and the instructor is at hand to give any needed assistance. Explanation of such work to the rest of the class is of rather negligible value, either to the man making the explanation or to the other members of the class. If classes exceed fifteen men, it is difficult for the instructor to give needed assistance. If grades are to be given on such work, it is rather difficult to estimate how much should be deducted for the instructor's help. Also, if another class follows immediately, proper grading of the work at the board is often impossible. No record of the student's work persists, so if the instructor makes a mistake in his hasty examination of the problem, the student has no redress. Blackboard solutions can not be filed for future reference.

Paper written work, especially for the purpose of grading the student, has nearly all of the advantages of blackboard work and some others of its own. It is not so easy for the instructor to see the work of each man and to give individual assistance, it is true, but for this very reason the result is a better measure of what the student has done. This method should not be used alone, but as supplementary to the lecture and class discussion mentioned above. Any difficulties or misunderstandings of the student should be cleared up in the part of the period preceding the written work. Mistakes on these papers should be marked, the papers graded and then handed back at the next class period. A delay in returning the papers dulls the effect of the corrections. By this

procedure, the student has a record of his work and of his instructor's estimate of his work. These he can study over to correct his mistakes and then he can file them for future reference.

No mention has been made of the laboratory or supervised study method of teaching mechanics such as has been used for a number of years at the University of Iowa, because the writer has had no experience with this method. It would appear to have some very good points in its favor, but is evidently not as economical either of the student's time or the instructor's efforts. It must be for some one else to say as to whether the superior results will pay for the greater time and effort spent by both the instructor and the student.

HOW MUCH DYNAMICS SHOULD BE INCLUDED IN THE COURSE IN ENGINEERING MECHANICS?

N. C. RIGGS

Carnegie Institute of Technology

The age in which we live is one in which speed has become of dominant importance. Both the speed and size of moving parts of machines have been enormously increased of recent years and the increase continues. Vibrations which at low speeds are relatively insignificant may now determine whether the machine will run or shake itself to pieces. Forces are introduced through high speeds that require the most careful design for safety. Unnecessary material may, in the wrong place, become a great danger, and lack of material at points made critical at high speed is fatal to the success of the machine. The designer must know what forces will be developed by rapid acceleration and high speed in order to provide for the stresses that will be introduced in the material. The old method of design by trial becomes too slow, too expensive, and too uncertain. The need then is evident for men well trained in dynamics. The mechanical, the electrical, and the civil engineer are all interested in the problem.

There seems to be considerable evidence that the graduates of our engineering courses are not, in general, well equipped in even the fundamentals of dynamics. Mr. G. B. Karelitz of the Research Department of the Westinghouse Company, writing in the December issue of *Mechanical Engineering*, says: "Much traditional opposition exists relating to the introduction of theory into the college training of mechanical engineers, because it is assumed that the engineer does not need this knowledge in his every-day activity. Dynamics is therefore listed as an advanced course, fit only for post-graduate work. However, industrial concerns find it advisable to go to the expense of training their young engineers in theoretical dynamics, the cost of such training being considerable when everything is taken into consideration." Mr. H. L. Whittemore of the Bureau of Standards at Washington, in commenting on Mr. Karelitz's article, says: "Apparently he has a very clear conception of the need for the more thorough theoretical training of mechanical engineers in mechanics. We have found here at the Bureau of Standards that engineering training which is apparently satisfactory in commercial work does not give the grasp of fundamentals which is desirable for our work. Please remember that many of our problems are very simple in comparison with those which occur in commercial work."

Other commentors agree that more training in dynamics is desirable for mechanical engineers.

Now I do not think that in the general course in analytic mechanics we can train our students to become experts in designing high speed machinery. Those who go into this sort of work will need an additional course in the dynamics of machinery and even then must, by working under experts, gain much of the necessary knowledge after leaving college. But I do believe that we can give our students a better grasp of some of the fundamentals and at least introduce them to more of the interesting problems that they will meet in practical work. Or, even if they become salesmen or operatives instead of designers, they will have had a glimpse of some

important and interesting engineering material, and an opportunity to sharpen their wits and to tax their ingenuity with some rather difficult problems.

Three elements come into the problem under discussion:
(1) The preparation of the student,
(2) The time allowance for the course in mechanics,
(3) The equipment of the instructor.

In the matter of the preparation of the student there is considerable variation. The course in mechanics may begin before the student has had a course in calculus or it may follow a thorough course in calculus in which some of the material of mechanics has been used as illustrative problems. Physics may or may not be a prerequisite of the course in mechanics.

In the matter of the time allotted for the course in analytic mechanics, there is again too wide a variation. Among the institutions represented at the Wisconsin Conference of Mechanics Teachers last summer it was found that the time for this course ranged from 51 class periods (three hours per week for one semester) to 110 class periods. Here certainly is a situation that needs attention. If mechanics is a fundamental of engineering, as we are accustomed to have it classed, and, of course, as all teachers of mechanics believe it to be, then there should be some approach to uniformity as to the place in the curriculum at which it occurs and as to the time allotted to it. I believe these to be two important points on which it would be very desirable for a future conference of mechanics teachers, such as is being considered by a committee of the Wisconsin conference of last summer, to make a thorough study and recommendation. Such a recommendation would, I believe, help in obtaining for the mechanics course the position that its importance merits and which in some institutions it does not now have.

Of no less importance to the success of the mechanics course is the equipment of the teacher. In order to give a thorough course in dynamics he must have a complete mastery of such material as is given in the commonly used textbooks, and

should have a great deal more. Of course if he has had practical experience along the line of his teaching his value as a teacher is greatly enhanced. The trouble here is that not many who have had really valuable and important positions in the industries feel the lure of the teaching profession. However well the teacher may know his material and however well he selects it, he must also have considerable skill as a teacher in order to succeed. I believe the teaching of mechanics to be hard work. The ideas must be clear and be clearly presented. The teacher must know when to pull and when to push.

Let us now assume that the teacher is well qualified, enthusiastic and energetic, and his students equipped with a fair knowledge of College Physics and Calculus. Further let us take what seems to be a fair average of the time allotted in several good engineering colleges; suppose the course in analytic mechanics and strength of materials to occupy two semesters of 5 recitation periods per week, or better, three semesters of 3 recitation periods per week, exclusive of laboratory work, with adequate time for outside preparation. What then should be the content of the course in dynamics? I believe that for all students taking the courses just mentioned the subject of dynamics merits one third of the time allotted. The students of mechanical engineering will need additional work in dynamics. With this amount of time at our disposal the course must be most carefully arranged and unessentials eliminated in order to cover the important principles and their applications. I would include the ordinary straight line motion and curvilinear motion in a plane, under the action of constant and variable forces. In straight line motion many interesting and practical problems in vibration can be arranged involving forces which vary with the displacement, either directly or according to some other stated law. These can be so stated that their solution involves far more than the substitution in formulas developed for constantly accelerated motion or simple harmonic motion. For example, the motion of a weighted piston in a closed vertical

cylinder enclosing a gas, with friction at the cylinder walls, is a problem which requires considerable thinking for its solution. Likewise such problems as that of a body moving vertically under the action of its weight and a variable air resistance require careful thought in writing the equations of motion and in their solution. In curvilinear motion, the simple pendulum, the simple governor, projectiles, and the motion of a particle along some restraining path, form good exercises for two or three recitation periods. Relative velocities and accelerations I believe to be important. Here such problems as the ice-boat and the motions of a crank-pin and connecting rod of a stationary engine are interesting applications. Work and energy deserves considerable time. Any number of interesting problems involving rotating and translating bodies and systems of bodies are readily available.

In the study of the motion of a rigid body it should be shown that angular velocity of a body is a vector quantity, and that the motion of a body which has one fixed point can be described as one of simultaneous rotations about three intersecting axes passing through that point. D'Alembert's Principle should be explained and the student should be required to solve several problems involving this principle, for such cases as the connecting rod and other bodies having plane motion. Finding the reactions of the support of a compound pendulum, or of a weighted shaft supported at two points are good problems involving work and energy and D'Alembert's Principle, using reversed effective forces. Finding the couple introduced by a rotating disk whose face is not perpendicular to the axis of rotation is another good illustration of the use of D'Alembert's Principle. I would include in the course the conditions of static and dynamic balance of a shaft with a few illustrative problems. I believe that impact, center of percussion, instantaneous axis of rotation, conservation of momentum, loss of energy in momentum, should find a place in the course, and that the course might well end with enough of the theory of moment of momentum, involving its vector nature, to explain the simpler motions of the gyroscope

and some of its simpler applications, such as its use in torpedoes and the gyro-compass.

That this would by no means prepare men for the advanced work in mechanics that some industrial concerns would like to have them enter is evident, but it seems to me to contain a certain minimum of dynamics which all engineering students should obtain, and is, I think, more than is obtained in the average course at present given. Additional courses in dynamics will be needed by those who hope to get a thorough enough and practical enough knowledge of the subject to enable them to work into the analysis of forces and stresses in present day high speed machines.

In closing I would express the hope that the teachers of mechanics will, from time to time, continue the conferences so well begun. The matter of the content of the course, not only in dynamics but in statics and strength of materials, the need of advanced courses in mechanics and the type of such courses, methods of conducting courses, and the preparation of teachers of mechanics, are some of the topics whose further study by a considerable body of teachers should result in substantial improvement in the teaching of a subject of fundamental and growing importance in the education of engineers.

THOUGHTS ON MATERIALS TESTING

By HERBERT J. GILKEY

Associate Professor of Civil Engineering, University of Colorado

For many years materials testing has been generally accepted as an essential part of engineering education and training. Nevertheless, there has evidently been a wide diversity of opinion as to just what the objective should be in teaching it. Most teachers have probably been but mildly aware of any lack of general agreement in method and purpose. Nevertheless, an inquiry would doubtless bring out a great variety of viewpoints and many who have been going through the motions for years might well begin to question whether the course, as they have conceived it, merits a place in the crowded present-day curriculum.

This diversity of outlook is no doubt partly due to and partly the cause of the fact that materials testing has not thus far seemed amenable to text book handling. Although excellent books on the subject have appeared from time to time, each laboratory for the most part continues to use its own mimeographed or printed notes. This is due in no small part, of course, to the difficulty encountered in making any one published work fit the individual laboratory layout. But another very important factor is the difference in emphasis and detailed ways of doing things. The work as handled still reflects the individual instructor's hobbies and background to a greater extent than do most of the other engineering courses.

Probably there is general agreement that the work in materials testing should supplement and augment the course in Mechanics of Materials. Moreover, it should develop "materials horse sense."

Beyond this common plank, platform architecture varies widely. Some consider each laboratory exercise a small en-

gineering project and require that the write-up be considered in the light of a formal engineering report, adequate in content and correct in form. Others practically ignore the report feature and almost anything passes providing a proper understanding of the problem is demonstrated. By some the manual aspects are emphasized and by others they are minimized. There are laboratories in which the test work is largely performed by the instructor while the class looks on. Some instructors believe in "turning them loose and telling them nothing," while others (too few in the writer's opinion) actually teach the course by explaining, questioning and building around the manual work performed. Final examinations are sometimes given in the subject but more often they are not. In certain cases considerable care is used to see that the report represents individual thought and work on the student's part, while the writer has known of cases in which a freshman was hired to copy the report of a preceding year. Although the time devoted to the materials testing work doesn't differ greatly, the apportionment of the time varies. There are instances in which the major emphasis is placed upon the performance of a very large number and variety of experiments often at the expense of thoroughness in the working up and interpretation. In other cases the number of experiments is not great but correspondingly more time is devoted to each. Instructors with a research bent may inject that element into the work (to the probable detriment of the course if it is attempted to have the class assist the instructor appreciably in the pursuit of his research hobbies).

In recent years there has been a tendency in some quarters to link the course with specifications for materials. Usually this has gone no farther than to compare the results of tests with the requirements of certain standards or specifications. It is of value to the student to do this because as a practicing engineer, he is most likely to use his knowledge of materials testing in this particular connection. Due to the fact that any specification is necessarily dry, terse, and arbitrary, the writer has felt that the interpretation of test results in the

light of a specification is likely to be a perfunctory and rather meaningless operation and that too often the student or the engineer will rate his own opinion above the specification because of a lack of understanding, appreciation, and respect for the specification. As a subject for graduate study, the writer believes that an analytical study of representative specifications with a view to comprehending the reasons back of them (their background) would be most profitable. Such a study would require too much time to permit its incorporation with the regular materials testing work without increasing the time allotted to it. The advisability of this is questionable and its feasibility doubtful.

In lieu of such a study the writer has substituted the alternative of making such a study illustrative rather than inclusive. He devotes the time ordinarily allotted to one laboratory problem to a detailed study of one representative standard or specification which may by inference be considered as typical of others.

The accompanying matter given in question and answer form represents the writer's effort to incorporate this phase in the teaching of materials testing. It will be especially noticed that the treatment has not been restricted to the specification features alone. If extra light could be cast upon the mechanics of the subject or questioning thought directed toward the mode of test procedure etc., the endeavor has been made to let the light so shine. In other words, the undertaking has not been limited to one objective unless it be defined as "An excursion to see all that can be seen." This has not, of course, been accomplished but it would probably be unwise to prolong the assignment too greatly. Perhaps some who agree with the purpose will favor a shortening in the execution. The appended material is not offered as a finished product. No doubt parts of it are wrong, since much of it is speculative. The material merely illustrates a type of thing that might be employed to add to what the engineering student obtains from his work in materials testing.

In line with the specification portion of the objective sought,

the writer considers it very much worth while that the students become thoroughly familiar with A. S. T. M. publications, realizing that there are also others in many specialized fields. Moreover, all students taking the work are required to read and assimilate Dudley's 1907 Presidential Address before the American Society for Testing Materials entitled "The Enforcement of Specifications" (*Proc. A. S. T. M.*, 1907, pp. 19–38). This has been copied and mimeographed for distribution.

The writer's thoughts were first directed along these general lines through his contacts with former co-workers H. F. Moore and F. B. Seely a number of years ago. The idea that the material might be of general interest to engineering teachers arises from the favorable reception at the hands of several to whom copies were sent for criticism. Mr. R. S. MacPherran, Chief Chemist of The Allis-Chalmers Mfg. Co. and Chairman of A. S. T. M. Committee A3 on Cast Iron, and Mr. C. L. Warwick, Secretary of the A. S. T. M. have both offered very helpful and encouraging comments. Mr. E. O. Bergman has rendered material aid.

Assignment No. 10

Detailed Consideration of a Typical Laboratory Experiment

Purpose:

Most experiments offered in the Materials Testing Course contain much unsuspected food for thought.

Concealed behind every well written standard or specification are numerous reasons and considerations rarely realized or appreciated, even by those who use them most.

In what seems to be only manual laboratory routine, basic principles and sometimes obscure theory of mechanics, are illustrated and demonstrated in ways that add much to their significance if one but pause long enough to consider thoughtfully the thing presented.

The experiment selected for dissection, while exceptional in none of these respects, does contain a fair proportion of material that should:

(*a*) Increase the appreciation of and confidence in specifications from authoritative sources, whether we understand the reasons back of them or not (for we usually will not).

(*b*) Arouse in us a speculative habit, a questioning attitude of mind, an intelligent curiosity.

(*c*) Drive home points from the mechanics of materials that were hastily passed over or, if understood, were still largely unappreciated and undigested.

The flexural test of an arbitration bar of gray cast iron is further adapted to the present study because of its apparent total lack of technical matter. It seems to be so simple as to merit no second glance.

Questions on:

The Test of a Pair of Arbitration Bars under A. S. T. M. Standard A48–18. Answers follow the list of questions. The student is held responsible for intelligent answers to all of these questions. They need not be written but there will be a quiz covering the field.

Referring to A. S. T. M. Specification Serial Designation: A48–18:

1. According to the definitions of the three classes of gray iron castings (Section 1) a large thin plate or massive casting weighing several tons, but having one thin section, would pass as a light casting, while a 2¼ in. cube or sphere would be a heavy casting.

(*a*) Does this seem to be a reasonable classification?

(*b*) Can you suggest a better one?

(*c*) Can you justify such a basis of classification?

2. Note Section 2 and the footnote. Is Section 2 a fair provision?

3. Why is the sulfur tolerance slightly higher for the heavy castings? (Section 4.) (Tolerance is defined as "the permissible deviation from some ideal or theoretical value." Zero would be the ideal sulfur percentage.)

4. In Section 5 (a) it is specified that the arbitration bars from light, medium and heavy castings take equal deflections but support different loads. Remembering that the bars are themselves all of the same size, why should the bar representing a heavy casting be required to support a center load of 3300 lb. against 2500 lb. for a bar representing a light casting? Are heavy castings necessarily subjected to more intense loading than light ones? (Note that the same kind of a differential is made in case the tensile test is used and in the tentative revision of A48–18.) (*Proc. A. S. T. M.*, 1927, Vol. I, pp. 1089–91.)

5. Why should there be a requirement regarding deflection and what properties of the bar are indicated by:

(a) Load it carries prior to fracture?
(b) Deflection it attains prior to fracture?
(c) Load and deflection considered together?

6. The arbitration bars are poured vertically. Would it be equally well to pour them horizontally?

7. Bars are cast in pairs. Only one bar of a pair has to pass the specified test. Why would it not be fairer to the purchaser, without unfairness to the producer, to require that both bars pass?

8. It is specified that the test bars be not removed from the mold until cool enough to be handled. State possible reasons.

9. Can one pair of bars simultaneously represent more than one kind of casting? Explain.

10. Below are typical results from arbitration bar tests. Specify which castings are acceptable and which should be rejected. State all reasons for failure of any bar.

Melt	Bar	Load	Deflection
1.....	*A*	3,350	0.11
	B	2,800	0.08
2.....	*A*	2,550	0.12
	B	2,700	0.10
3.....	*A*	2,300	0.12
	B	3,250	0.09
4.....	*A*	3,300	0.12
	B	3,350	0.10

11. A picture is shown of the tension test specimen that may be used at the purchaser's request and expense.

Why is it threaded at the ends instead of smooth to be gripped with the usual wedge-shaped V-grips?

12. The gage length is very short (1 in.). Is there any apparent justification for this when it is considered that the usual gage length of a tensile specimen is either 2 in. or 8 in., the latter being the more common for some grades of steel?

13. The diameter at the reduced section is 0.8 in.

(*a*) Could it be appreciably larger?

(*b*) Is there any reason why it should not be appreciably smaller?

(*c*) Does 0.8 have any advantage over 0.85 or 0.75 in.?

14. Cast iron is weak and unreliable in tension. It is often used where there is some flexure but with a high safety factor. It is at its best in compression.

The standard test specified is flexural. An optional tension test is allowed.

(*a*) If the material is best suited to resist compressive stress, why isn't a compressive test specified, either as the major test, or as a secondary optional test?

(*b*) Can you see anything to justify a tensile test as a basis for acceptance or rejection of castings that are unlikely to be used in direct tension, regardless of their nature?

15. Is it essential that a material be tested in the way that it is to be used?

16. The arbitration test consists in loading to failure a beam of cast iron, circular in cross-section, with a concentrated load at the center, on a 12 in. span. Stresses in beams are computed by the formula $S = Mc/I$. From these data and this formula, can the ultimate strength of the cast iron be computed?

17. Any member in flexure is subjected to both tensile and compressive stress. If the material be not equally strong in tension and compression, it will fail when the ultimate strength in the weaker way is reached. It would therefore appear that $S = Mc/I$ for the arbitration test bar should equal the ultimate tensile strength of cast iron. If this be not true, explain.

18. Suppose that there were poured from the same melt iron bars of the following descriptions:

(*a*) Same diameter but twice as long as the arbitration bar.

(*b*) Round bar same length but 2 in. in diameter.

(*c*) Square bar same length and area cross section as arbitration bar.

(*d*) Square bar same length and section modulus as arbitration bar.

Are these bars truly comparable with the regulation bar on the basis of their modulis of rupture as computed by the flexure formula? State each of the several influencing factors in case there be more than one.

19. Can the value of the modulus of elasticity of this cast iron be computed from the formula $E = Pl^3/48Iy$? Explain.

20. If it be desirable to know the modulus of elasticity for this iron, how may it be best obtained?

21. Insofar as acceptance or rejection of castings is concerned, does one need to know the modulus of elasticity, or the modulus of rupture of the metal?

22. Is there anything in making the flexural test or in the interpretation of its results, that an average, honest workman could not perform as efficiently and correctly as a skilled inspector, tester or engineer?

23. It is specified that the bar "shall not be rumbled or otherwise treated, being simply brushed off before testing." This means that the surface will be rather rough and pitted. (*a*) If you wish to compute the modulus of rupture of the bar it will be necessary to measure it. To what refinement would you be justified in measuring the diameter?

(*b*) Why should the bar not be rumbled?

*24. (*a*) Where would you take the cross-sectional measurements? (Note that the bar is to be 1/16 in. smaller at one end than at the other. Would you therefore measure it at the smaller end, in your attempt to know the dimensions at the critical section?) Explain.

(*b*) Discuss lack of roundness, its effect, and proper allowance for it.

25. Suppose that there is an obvious reduction in size at the quarter point. Should that be measured in anticipation of failure occurring there?

26. Dimensions for the bar are given in Fig. 1. (*A* 48–18). The exactness of measurements is always relative. In the case of a rough casting, such as the arbitration bar, the fluctuation one side or another from the theoretical dimensions is likely to be quite appreciable. Yet nowhere in the specification are any tolerances stated. Since a large bar will carry more load than a smaller one, what is to prevent the manufacturer from cautioning his pattern maker to construct the pattern a little oversize? (Even if the inspector noticed that the bars were running a bit large, the manufacturer could reply that it was accidental and request the inspector to show him where in the specification any limitation was set upon the permissible overrun.) †

27. A slight error in the span would make an appreciable difference in the load carried. Is there here involved any element of compensation?

28. The present test and the preceding questions have pertained to gray-iron castings. Are standards given for any other grades or types of cast iron?

29. Are the kinds of strength test and types of specimen either identical or similar to the arbitration test of A48–18?

* The new specification, as being revised, will state that measurement shall be taken at the point of application of load, *i.e.*, at midspan.

† A table of correction factors is being added to the new specification.

30. Why would it not be better to test all cast iron products against A48–18 instead of multiplying the standards by having special requirements for certain types of castings?

31. Which is the stronger material: cast iron for pipe larger than 12 in. in diameter, or cast iron for heavy castings? Why should there be a difference?

Discussion and Partial Answers to Questions

1. (*a*) This specification covers a very broad field. Gray iron castings are infinite in their variety of shape, relative proportions, and size. The range of use is equally great. Some large castings may never be called upon to support external loads of any considerable magnitude as compared with the supporting power of the casting. Others may be worked right up to the limiting stresses permitted. The same applies to small castings. Some castings may be carefully designed from the stress standpoint and others may of necessity contain a considerable body of material that is subjected to low and practically negligible stress. Realizing that either extreme of the stress condition may exist for either a very large or a very small casting it is apparent that any definite classification of castings, in general, from the standpoint of shape, size, or use, is difficult. The present classification evidently represents the best judgment of the committee, formulating the specification, after consideration of the several factors involved. Evidently the internal stress condition, always so important in castings, is partially dependent upon the mass of the material and partially upon the distribution of the mass, which includes the relation of surface area to volume, degree of abruptness at changes of section, etc. While there are doubtless many forms of casting, such as the small 2¼ in. diameter sphere (a heavy casting) *vs.* a thin plate of large area or two heavy masses connected by a thin neck (a light casting), which may seem to violate the purpose of the classification, it is probable nevertheless that the classification adopted is as fair as any that could be devised without greatly complicating the subject. Other possible bases for classification and some of the objections to them are:

(1) By weight (actual or computed) which considers only the amount of the metal. No account taken of shape, surface area or distribution.

(2) By volume. Same objections.

(3) By surface area. Takes no account of shape, abrupt changes of section, or concentrations of mass.

(4) By use. Too diversified. Impossible to classify.

It is true that the present classification does not take full account of any of these factors but it probably comes nearer to doing so than do the others suggested.

(*b*) If you feel that you can suggest a better classification for castings than that of A48–18, after duly considering the points touched upon in 1 (a) please do so. It is entirely possible that there be undiscovered opportunties for improvement.

(*c*) If the present classification can be justified further than has already been done under 1 (*a*), explain how. If you had a suggestion to offer under 1 (*b*), justify it.

2. The preparation of the tensile test specimen will entail delay since machining is necessary. There will be added cost. More elaborate stress-applying and strain-measuring devices are required. If the purchaser is not satisfied with the test that has been accepted as standard, it seems reasonable that he should bear the cost and stand the delay of the substitute test. On the other hand there is no valid reason why the producer should desire to sidestep the requirement that his product measure up to that called for in the standard test. It is the cheaper and simpler test for him to make and there is no evidence that an inferior grade of material would fail the flexural test and pass the tensile.

3. In the heavy casting there is a greater concentration of metal at minimum cross-sections. Local sulfur segregation is not likely to influence the strength across the section to the same extent as it might if the minimum cross-section were thinner. This applies especially to the "hot-shortness," *i.e.* the danger of cracking, while hot, or from cooling stresses.

4. In a heavy mass of metal, cooling stresses are much greater than in small masses which undergo a less total shrinkage and all parts of which come nearer to reaching the solid state simultaneously. Initial stresses are present in all unannealed castings but the heavy casting may be weakened to a relatively greater extent. In an effort to compensate for the greater intensity of shrinkage stress it is required that a better grade of iron be used in heavy castings than in light ones. The same pair of arbitration bars that came from a melt in which both heavy and light castings were poured may give an indication that will pass the light castings and reject the heavy ones. While the higher internal stress condition is the major factor, it is not the sole one. Large blow holes are less likely to be present in light than in heavy castings. The interior of a heavy casting cools much more slowly

than the interior of a light casting and the crystalline structure of the former will be much coarser and therefore weaker. Segregation will be more pronounced because of the larger mass of metal that remains in the molten state for a longer time. (Does this last point appear to be in conflict with Explanation No. 3? Can you harmonize the two?) None of the internal differences between light and heavy castings appears in the comparative tests of arbitration bars for they are all the same size and cool alike. Thus the stronger metal from the bar tests may actually produce the weaker casting (per unit of metal) due to the discounting effects of shrinkage stress, coarser structure, blow holes and segregation. (See also the discussion under Answer No. 1.)

5. At best cast iron is a brittle material. It is the lack of flexibility, resilience and toughness that makes it unsuitable for many uses. The deflection requirement sets a minimum limit on flexibility or a maximum limit on brittleness.

(*a*) The load is an index to the strength of the material.

(*b*) The deflection is an index to elasticity and ductility. The ultimate deflection does not separate the elastic from the nonelastic deformation so the total ultimate deflection is a measure of the combined properties of elasticity and ductility. Cast iron is very deficient in both of these properties. The deflection sets a minimum limit upon their combined value just as the load sets a minimum strength requirement.

(*c*) Strength in conjunction with deformability is an index to resilience and to toughness. Elastic deformation and stress carrying capacity give resilience, and nonelastic deformation (ductility) and strength give toughness (the opposite of brittleness). High work-absorbing capacity means high resistence to impact or shock. The measure given by ultimate deflection and ultimate load represents the combined effect, *i.e.* resilience plus toughness. To be tough it is not enough that a material be simply strong.

6. If poured horizontally the top and the bottom of the bar as poured would be materially different due to:

(*a*) Differences in rate of cooling.

(*b*) Segregation.

Thus the same bar might give different flexural strengths dependent upon the side that was up or down at test. End pouring insures uniform treatment, in these respects, for each point in a given cross-section. It facilitates the removal of blow holes by permitting them to rise to the top of the bar as poured. The top is an overhanging end as tested.

7. It is recognized that even good commercial castings will

contain some imperfections in the way of blow holes and flaws. It is always possible that one of those may be located near enough to the section of maximum bending moment to show a reduced strength because of it. It is highly improbable that both bars from a pour, if of good average material and workmanship, would contain an accidental blow hole or flaw at the critical section. Thus the provision that but one bar of the pair need pass the test would appear to be fair to the producer without unfairness to the purchaser.

8. Any chilling greatly affects the properties of the iron. Bars to be comparable should have like treatment during cooling.

9. Yes. Conceivably one pair of test bars could represent many castings of light, medium, and heavy grade if all were poured from the same melt. (See also Answer No. 4.)

10.

Melt	Bar	Load	Defl.	Results	Conclusion
1	*A*	3,350	0.11	L.M.H. passed	Accept all castings *
	B	2,800	0.08	Failed, Def. low Low load M.H.	
2	*A*	2,550	0.12	Def. O.K.; L. passed load	Accept light castings*
	B	2,700	0.10		
3	*A*	2,300	0.12	Failed, load low	Reject all castings
	B	3,250	0.09	" def. "	
4	*A*	3,300	0.12	L.M.H. passed	Accept all castings*
	B	3,350	0.10	" "	

11. Brittle materials such as cast iron or cast steel, high carbon steel, etc., shatter or break, at or in the grips if the attempt is made to use the wedge grips. As stated in the footnote to Section 2 (A48–18) special precautions must be taken to eliminate bending in making the tensile test. These precautions include the threaded end to screw into spherical seated holders. Local crushing of high intensity, such as the wedge grips give, is liable to make the piece shatter by a tension failure at right angles to the pair of crushing forces, even if perfect alignment could be obtained with the wedge gripping. Cast iron is only about one fifth as strong in ten-

* Of course no casting is acceptable if it fails to conform to Section 10 (A48–18).

sion as it is in compression. Poisson's ratio has a bearing in this connection. Can you explain?

12. The longer the gage length, the greater the chance that a blow-hole or local defect may lie concealed within it. Furthermore it is specified that the tensile specimen shall be turned from one of the broken pieces of the transverse specimen. In many instances it would not be possible to obtain a piece, free from flaws and suitable for turning down, that was much longer than the 3.5 in. over-all that is specified. In general the 3.5 in. length makes possible a selection from either three or four pieces from which at least one satisfactory specimen will be usually procurable.

13. (*a*) Not with the amount of reduction specified since the out to out measurement of threaded ends equals the nominal diameter of the bar (1¼ in.).*

(*b*) Probably the diameter along the gage length should not be appreciably smaller for the following reasons:

(1) More machining would be required.
(2) The metal at the center of the bar is coarsest and it is probable that a test piece wholly from it would not give as representative a measure of quality.

(*c*) The 0.8 diameter gives an area of almost exactly one half a square inch (0.503) which is a very convenient one to use. This probably constitutes the main advantage over 0.85 or 0.75 in.

14. (*a*) Probably the compressive test was the first one seriously considered by the committee. Its non-adoption was doubtless from the considerations of (1) cost; (2) non-feasibility; and (3) unreliability. These will be further considered.

In materials testing laboratories the 100,000 lb. machine is probably the commonest. Cast-iron in compression has an ultimate strength of about 100,000 lb. per sq. in. Thus in such a machine a test piece of one inch square or a circular prism about 1.1 in. in diameter would be a capacity load.

In order that a compressive specimen give an indication of compressive strength and not of combined compression and flexure as in a column, the height should not exceed about twice the diameter. Thus if a 100,000 lb. capacity machine

* There is pending a tentative revision to this standard which will reduce the nominal diameter from 1¼ in. to 1.20 in. and which will also reduce the over-all diameter of the tensile specimen to 1⅛ in. (See *A. S. T. M. Proc.*, 1927, Vol. I, pp. 1089–91, also question No. 29.)

were to be used the limiting height of specimen would be less than three inches. (If a 200,000 lb. machine were used it would be less than four inches.)*

Either of these gives a very short gage length. If strains as well as stresses are to be obtained (and they must be if the modulus of elasticity or any other measure of flexibility is to be had) a very delicate compressometer will have to be used. The compressive testing head is very much in the way and it is not possible to have the specimen situated for ease of observation as in the tensile test. The specimen is brittle, it has no yield point and failure will come explosively at maximum load and without warning. There will be more shattering and instrumental hazard than in the case of the tensile failure, which is far less likely to damage the extensometer, sensitive though it is.

In any compressive test proper application and alignment of load is much more difficult than in tensile tests. The ends of the specimen must be perfectly plane and at right angles to the vertical axis. It must be perfectly centered under crossed knife edges or a spherical bearing block of diameter not appreciably in excess of that of the specimen. While it is difficult to align perfectly the tensile specimen (see footnote under Section 2, A48–18) it is much more difficult to obtain a fair compressive test on a small specimen of such material.

In either the direct tensile or the direct compressive test, the strain measuring apparatus will have to be very sensitive (but with much more danger of injury in the latter test). It must give reliable readings to one ten thousandth of an inch or less. In the flexural test the deflection greatly exceeds the longitudinal lengthening or shortening. For example consider a string to be stretched between supports 12 in. apart. If the string be deflected 0.1 in. at the center (which is the minimum required deflection for the arbitration bar) the change in length has been but $2\sqrt{36.01} - 12 = 0.00164$ in. in 12 in. or an average unit elongation of 0.00014. From this approximate computation it is apparent that a deflection measurement to the nearest 0.01 in. supplies an accuracy comparable to a longitudinal measurement to the nearest 0.000014 in. on a one inch gage length, or 0.000028 in. on a two-inch gage length, etc. Thus a very crude, simple and rugged deflectometer reading to the nearest 0.01 in. supplies strain data

* Note that longer conpressive specimens may be used (E9–27T, Section 4 and Fig. 1, *Proc. A. S. T. M.*, 1927, Part I, p. 1082). In such a case, this point becomes inapplicable.

as reliable as that to be obtained from the use of a very costly and delicate compressometer or extensometer requiring skilled and careful manipulation.

In like manner the compressive test requires a costly machine of high capacity (100,000 lb. a probable minimum). The tensile test can be performed on a machine under 15,000 lb. capacity while a 5,000 lb. hand power machine is more than adequate for the specified flexural test. There are on the market simple arbitration test bar machines, autographic and hand operated. A pencil moves in one direction in proportion to the load and in the other proportional to the deflection. At slight cost the foundry can possess such a machine. Any ignorant but honest laborer can operate it and he can tell at a glance whether the bar passed or failed. The order or melt number can be written on the autographic record and it can be filed for future reference. Properties of the bar can be easily computed from the load deflection graph so obtained in case more than the mere acceptance or rejection data are desired.

Practically no labor cost has been expended in casting the arbitration bars. No subsequent cost for machining or finishing has been entailed. There is no materials cost since the broken fragments go back for remelting. From the standpoints of feasibility and cost the tensile test is far superior to a compressive test and the flexural test is preferable to both. But cost and feasibility are subordinate to another point that has not yet been considered. Do those tests furnish the information desired? Is the ability to pass either of them reliable evidence that the iron will make good castings? The tests are valueless if they fail to furnish this needed information. The experimental evidence seems to indicate that good iron in tension or flexure is good iron in compression and that practicability and economy are therefore proper criteria for choosing from among the three tests considered. The weight of evidence is all in favor of the flexural test.

(*b*) Largely answered in the paragraph above. A test need not necessarily resemble the use, providing it gives reliable evidence as to suitability for that use. If red apples always have the desired flavor, then a color test may be a suitable one for the selection of eating apples. If the strength of steel is always proportional to the Brinell harness number, the Brinell hardness test may in some cases be preferable to a strength test as a measure of the strength of steel. On occasion it has been so employed.

15. No. (See 14 b.)

16. One of the basic assumptions underlying the derivation of the flexure formula $S = Mc/I$ is that stress is proportional to strain, *i.e.*, the material is not to be stressed beyond its proportional elastic limit. The proportional elastic limit for most structural materials (including cast iron) is well below the ultimate strength. It therefore appears that the flexure formula will not give correct values for stresses in the realm of ultimate loads. The quantity (sometimes designated as S_f) so obtained is called the modulus of rupture and may be defined as *"a fictitious ultimate fiber stress in bending."* Its value will usually be between the ultimate tensile and ultimate compressive strengths as determined by direct test. It is a very useful figure for comparing the strengths of members of similar size and shape tested under the same conditions of loading. Under these limitations the specimen that carries the greater load, *i.e.* has the larger modulus of rupture, is of the stronger material. If shape, span, type of loading, etc., be not identical the above conclusion may be incorrect. The answer to the question is, therefore, that the ultimate strength of the cast iron cannot be computed by the flexure formula. It is known, however, that the arbitration bar that carries the heaviest load is of the strongest iron (barring flaws and inequality of size, shape, or type of loading).

17. Ultimate strengths and modulus of rupture of gray cast iron are about as follows:

Compression 90,000–100,000 lb. per sq. in.

Tension (Sec. 6 A48–18) 18,000–24,000 lb. per sq. in.

Flexure (Mod. of Rupt.) 39,000–52,000 lb. per sq. in.

The minimum and maximum values, for tensile strength and modulus of rupture given, correspond to the minimum requirements for light and heavy castings respectively. It is apparent that the modulus of rupture greatly exceeds the tensile strength, lying between the ultimate tensile and ultimate compressive strength as stated in Answer No. 16.

This does not mean that any of the material in the bar has actually withstood a tensile stress in excess of the 18,000 to 24,000 lb. per sq. in. that this grade of iron is capable of carrying. This apparent contradiction with fact is explained as follows:

In the mechanics of materials it was demonstrated that the neutral axis of any cross-section of a beam contained the center of gravity of the cross-section. This proof was one of the early steps in the development of the flexure formula. Thus the correctness of the flexure formula is dependent, among other things, upon the truth of this demonstration.

But the demonstration itself was based upon three prior assumptions or conditions, viz:

(1) A plane section of the beam before bending remains a plane section after bending, i.e. deformation varies as the distance from the neutral axis.

(2) Stress is proportional to strain, i.e. the proportional elastic limit is not exceeded.

(3) The modulus of elasticity in tension equals that in compression.

Building upon these three assumptions we reach the conclusion that stress, either tensile or compressive, is proportional to the distance from the neutral axis of the cross-section. The violation of any of these conditions, stipulations, or assumptions necessarily invalidates the conclusions based upon them.

Condition No. 1 seems to be reasonably true for both elastic and non-elastic deformations. It is based solely upon experimental observations consisting of carefully made measurements of deformations at different distances from the neutral axis. It is a matter of observation rather than one of reason or logic.

The violation of stipulation No. 2 has already been established under Answer 16, for we are dealing with the ultimate load and the proportional elastic limit was long since exceeded. Assumption (3) is probably untrue for cast iron within even the elastic range of stress and for stresses exceeding the elastic limit there is no fixed ratio of stress to strain and there is, therefore, no modulus of elasticity in either compression or tension in the usually accepted sense. There will be, of course, successive relations between stress and strain but the value of the ratio will not be even approximately a constant over any non-elastic load range.

From the foregoing it is evident that the neutral axis of the cross-section cannot be expected to remain fixed or to pass through the center of gravity. Nor does it. It shifts, as the load is increased, toward the stronger or stiffer side. In this case it approaches the compressive face. The actual area under compression is diminishing while that subjected to tension increases. But the total compressive stress within the bar must equal the total tensile stress.* Thus the intensity of tensile stress on the increased area subjected to

* This is a basic fact of statics. The bar is in equilibrium. Therefore $\Sigma H = 0$. But the only H forces are the internal stresses and T (the total tension) must equal C (the total compression). Refer to the mechanics of materials for further demonstration.

tension will be less than the intensity of the compressive stress on the lesser area. The true tensile stress of the lowest fibers at failure doubtless approximates the 18,000 to 24,000 lb. per sq. in. while the true compressive stress may or may not be close to 90,000 or 100,000 lb. per sq. in. The flexure formula from which the modulus of rupture is computed persists in its assumption of equal areas subjected to tension and compression and this assumption gives an apparent compressive stress intensity that is too low and an apparent tensile stress that is too high.

18. They are not.

(a) The comparison is on the basis of ultimate loads in non-elastic territory and the flexure formula is, therefore, not applicable to any of these cases as covered in detail under Answers 16 and 17. The inapplicability of the flexure formula will not be influenced to the same extent by differences of span, diameter, shape and section modulus. Thus while bars of the same shape, span, size and loading can be fairly compared as to ultimate strength when strength of the material is the only variable, the comparison is invalid as soon as any other variable is introduced. For this reason alone the different bars will not give equal values for moduli of rupture.

(*b*) In the case of (*b*), (*c*), and (*d*) bars there is another difference. The bars differ in size or shape, or both, from the standard bar. As previously pointed out, the same molten iron may form different grades of cooled material. The surface of a casting differs from the interior in grain, size, etc. Thus the relation of skin or surface material to volume of the interior has its bearing upon the load that the bar will support.* In spite of these several factors the modulus of rupture often serves as a fairly accurate basis for comparison. In making such comparisons, the inherent inaccuracies should not be overlooked.

19. Not for the ultimate load since this formula, like that for flexure, is derived on the assumption that the proportional elastic limit is not exceeded. This expression is a special case of the "equation for the *elastic curve* of a beam carrying a concentrated load at the center." If the value used for P be not the ultimate load carried but be such that the material is not stressed beyond its elastic limit then a proper value for E can be obtained. As stated in Answer

* A tabulation of experimental results from tests on the affect of shape, at constant span, on the modulus of rupture, is given on page 122, Johnson's "Materials of Construction," 5th Edition.

16, the value of E for cast iron, even within the elastic range, is probably not the same in tension as in compression. The value obtained in flexure would approximate a mean between the other two. It is the one generally used. It should also be borne in mind that materials such as cast iron, timber, concrete and stone are not perfectly elastic within any range of stress but are approximately so and are so considered at relatively low loads.

20. The tangent modulus may be best obtained by drawing a tangent to the plotted load deflection curve at the origin and selecting a convenient value for deflection with the corresponding value for the load, these being substituted in the formula mentioned under 19. The secant modulus is obtained in a similar manner but the straight line used is drawn from the origin to some arbitrarily selected load part way up the curve. The secant modulus will always be somewhat less than the tangent modulus since the secant will make a greater angle with the vertical.

21. No.

22. The specification as stated is so simple that a very ignorant person need encounter no difficulty in its interpretation, its application or its enforcement. It is evident that much of its significance will be appreciated by relatively few.

23. (*a*) Measurement to 0.01 in. is as close as is justified.

(*b*) Experiments show that an average increase in strength of about 15 per cent may be expected from rumbling or tumbling. This is possibly due to a partial relieving of internal stresses.

24. (*a*) Under the loading specified the maximum bending moment will be at midspan. The very slight taper is negligible in comparison with the great change in bending moment along the bar. The diameter at midspan is, therefore, the one to be taken. See footnote under question 24.

(*b*) In the case of the arbitration bar and most specimens that depart but little from equality of diameters in directions of width and depth, it is proper to take the mean of two diameters at right angles to one another, as the diameter of specimen. If the two diameters vary from one another by any appreciable amount this procedure is not valid since strength varies as the square of the depth, and directly as the width. Stiffness varies directly as the width and as the cube of the depth. In such a case the values of depth and width could be weighted in proportion to their respective powers and averaged, or the computations could be based upon the actual dimensions in directions of width and depth. In

the present instance the slight lack of roundness of bars and the refinement warranted necessitate no precautions beyond use of a straight average of two diameters at right angles taken at midspan.

25. The bending moment at the quarter point is but half that at the center. The reduction would therefore have to be considerable in order to hazard the quarter point. If it were so great, probably the bar should be rejected. A measurement could be taken there, however, if desired. This feature is entirely apart from the specification requirements and individual judgment in the light of the ends desired should govern.

26. The larger the bar the greater the load it will carry but on a given span it will deflect less. If the manufacturer favors himself on load he is assuming greater risk of not attaining the required deflection. Thus there remains no incentive for him to attempt to produce bars either larger or smaller than the nominal dimensions specified.*

27. Yes. Analogous to 26. Increase of span will decrease the load and increase the deflection. No reason exists for intentional alteration either way.

28. Yes. (1) A44–04 Cast-Iron Pipe and Special Castings.
(2) A74–18 Cast-Iron Soil Pipe and Fittings.
(3) A45–14 Cast-Iron Locomotive Cylinders.
(4) A46–24 Chilled Cast-Iron Wheels.
(5) A47–27 Malleable Castings.
(6) A48–18 Gray-Iron Castings.
(7) A88–24 High-Test Gray-Iron Castings.

29. In some cases, similar; others widely different. See tabulation.

30. A48–18 covers a vast range of castings. In many cases it is advantageous to vary the test employed for certain special purpose castings. All the differences are not traceable to this source however. These several standards were developed at different times by different committees and varied points of view and approaches to the problem gave rise to varied standards. Insofar as a single standard can be made to cover the territory now covered by two or more, the trend will doubtless be toward the elimination and harmonizing of standards. It should be noted (see tabulation) particularly that the standard under discussion (A48–18) as well as

* The new specifications are obviating any slight injustice that might result from accidental variations by appending a table of correction factors based upon experiments.

REPRESENTATIVE CAST IRONS. A. S. T. M. STANDARDS, 1927

No.	Name	Specimen						
		Shape Cross-Section	Dia. or Dimen. (in.)	Span (in.)	Min. Deflect (in.)	Min. Load (lb.)	Ult. Tensile Str.	Mod. of Rupture † Computed
A44-04	C. 1 pipe up to 12″	Rect.	2 wide by 1 thick	24	0.30	1,900	—	34,200
A44-04	C. 1 pipe over 12″			"	0.32	2,000	—	36,000
A45-14	Loco. Cycls.	Round	1.25	12	0.09	3,200	—	50,250
A46-24	Chilled Car Wheels. Drop test on car wheel itself. No. spec.							
A47-27	Malleable Castings	—	—	—	—	—	50,000	—
A48-18	Gray Iron Castings (L)	Round	1.25	12	0.10	2,500	18,000	39,200
A48-18	Gray Iron Castings (M)	"	1.25	12	0.10	2,900	21,000	45,500
A48-18	Gray iron castings (H)	"	1.25	12	0.10	3,300	24,000	51,800
*A48-18	Tentative Revision (L)	"	1.20	18	0.20	1,500	18,000	39,800
"	" " " (M)	"	1.20	18	0.20	1,750	21,000	46,500
"	" " " (H)	"	1.20	18	0.20	2,000	24,000	53,100
A74-18	Soil Pipe	"	1.25	12	0.10	2,500	—	39,200
" *	Soil Pipe tent. Rev.	"	1.20	18	0.20	1,500	—	39,800
A88-24	High Test Gray Iron	"	1.25	12	0.12	3,800	28,000	59,600
" *	High Tent. Rev.	"	1.20	18	0.24	2,250	28,000	59,600

* *A. S. T. M. Proc.*, 1927, Vol. I, pp. 1089–91.
† Modulus of rupture computed from specified spans and loads. Not given in standards.

A74–18 and A88–24 are now (April 1928) under consideration for revision. (*Proc. A. S. T. M.*, 1927, Vol. I, pp. 1089–91.)

Referring further to the tabulation of question 29, differences may be noted and in some instances they can be explained.

A44–04 (Cast Iron Pipe) differs from all others in type of specimen. This is one of the earliest of the cast iron standards. The flat rectangular specimen resembles the metal in a strip of pipe. Note that the requirement for large pipes is more severe than for small ones which is quite analogous to the light, medium and heavy classification of gray iron castings. The moduli of rupture are somewhat below those computed for any of the other flexural specimens. No tensile test is offered.

A46–24 (Chilled car wheels) requires no specimens other than wheels themselves selected at random from finished lots. These wheels are subjected to various tests among which the drop test furnishes the index to strength, toughness and general capacity for withstanding the requirements of normal service. In a product as uniform in shape, nature and size as are car wheels, this procedure appears to be more direct and satisfactory than to test samples of some artificial form. This is a case in which it seems possible to standardize a test upon the product itself, an end always to be desired but rarely practicable.

A47–27 (Malleable Castings) resembles steel more than it does cast iron and the specified tests and properties are similar to those for certain grades of steel. There is no flexural test.

The tentative revisions of A48–18 are evidently designed to hold present required properties practically constant but to augment deflection and decrease load by a decided increase of span and a slight decrease in diameter. The moduli of rupture on the basis of the revision are nearly identical with present requirements. The change involves no basic considerations and none of the foregoing discussion is invalidated by such a change as that proposed. It is simply an exchange of load for deflection.

Identical tentative alterations are proposed for the arbitration bars for Soil Pipe (A74–18) and High Test Gray Iron Castings (A88–24.)

As would be expected the requirements A88–24 are more rigorous than those for any of the other grades of cast iron listed.

31. Impossible to say with accuracy since the specimens

" *	High Tens. Rev.	"	1.20	18	0.24	2,250	28,000	59,600

* *A. S. T. M. Proc.*, 1927, Vol. I, pp. 1089–91.
† Modulus of rupture computed from specified spans and loads. Not given in standards.

are of different size, shape and span. Compared from the standpoint of moduli of rupture:

For heavy castings (A48–18) $S_f = Mc/I = 51{,}800$ lb. per sq. in.

For cast-iron pipe larger than 12 in. $S_f = Mc/I = 36{,}000$ lb. per. sq. in.

Although the 51,800 and 36,000 lb. per sq. in. are not exactly comparable, as stated, the difference is sufficient to indicate that the heavy gray iron casting calls for stronger iron. This is explained by the relative thinness of the pipe wall as compared with the usual heavy casting. The shrinkage stress in the pipe will be less, the structure finer, and chance for segregation and large blow holes not so great. Perhaps all of the above reasons do not apply and there may be others not mentioned.

Conclusion.—The major portion of this paper has been devoted to an illustrative, detailed consideration of a typical laboratory experiment and an allied specification. The announced objective was: "An excursion to see all that can be seen." The end desired is not so much to alter the conventional course in materials testing, as it is to have it subjected to this same type of questioning scrutiny. Let each interested teacher re-examine his course and his objectives with a view to either justification or improvement. If, in addition to arousing inertia-dispelling doubts, some of the material suggests tangible betterment, the objective of this paper will have been more than attained.

A PROOF FOR MAXWELL'S THEOREM OF SUPERPOSITION BY THE METHOD OF AREA MOMENTS

BY M. M. FROCHT

Assistant Professor of Mechanics, Carnegie Institute of Technology

In the study of deflections frequent use is made of the principle of superposition, which states that the deflection of a point in a beam due to several loads acting simultaneously is equal to the sum of the deflections which would be caused at the given point if the same loads were acting separately.

This principle is known as Maxwell's Theorem. It is a special case of the more comprehensive Reciprocal Theorem proved by Lord Rayleigh.* Föppl also discusses this theorem in relation to Castiglianno's principle of Least Work.† Our texts, however, state this theorem generally without proof, treating it as an axiom whose truth has been amply substantiated by experiment.‡

An elementary proof is here submitted for a beam supported at the ends and carrying co-planar loads. The beam is also assumed to be of uniform cross-section and homogeneous. This proof, to the best of the writer's knowledge appears here for the first time.

AB is a straight beam carrying a single load P_n, where n is a positive integer. Corresponding to this load we adopt the following notation:

D_n represents the deflection of point B from a tangent at A,
e_n " " " " " " C " " " " "
y_n " " " " " " C,
d_n " " segment of the perpendicular from C to the line AB, intercepted between the line AB and the tangent AE.

* See "Applied Elasticity," by Timoshenko and Lessels.

† See "Vorlesungen Uber Technishen Mechnik," page 173, Vol. 3, 4th edition, Föppl.

‡ See "Strength of Materials," Boyd, page 283, 2d edition.

$\Sigma_C^A M_n$ represents the area-moment about C of the bending moment area between C and A, and $\Sigma_B^A M_n$ represents the area-moment about point B of the area between points B and A.

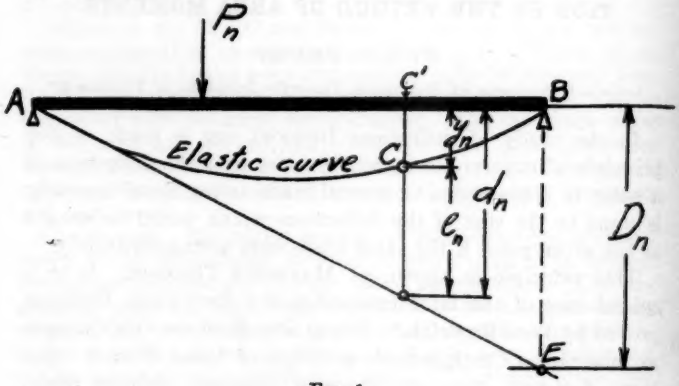


FIG. 1.

When k loads act simultaneously we will indicate this by changing the subscript from n to $1 - k$, thus:

D_{1-k} represents the deflection of B from a tangent at A due to k loads acting simultaneously,

e_{1-k} represents the deflection of C from a tangent at A, etc.

AUXILIARY THEOREM

The deflection of any point C from a tangent at A, Fig. 1, due to several loads acting simultaneously at different points equals the sum of the deflections of C from a tangent at A due to each load acting separately, or in terms of the notation agreed upon,

$$e_{1-k} = e_1 + e_2 + \cdots + e_k \tag{1}$$

By the principle of area-moments we have

$$e_1 = \Sigma_C^A M_1/EI, \tag{2}$$

$$e_2 = \Sigma_C^A M_2/EI, \tag{3}$$

and

$$e_k = \Sigma_C^A M_k/EI. \tag{4}$$

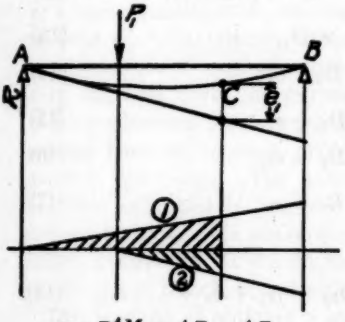
Adding we obtain

$$e_1 + e_2 + \cdots + e_k = (\Sigma_C^A M_1 + E_C^A M_2 + \cdots + \Sigma_C^A M_k)/EI \tag{5}$$

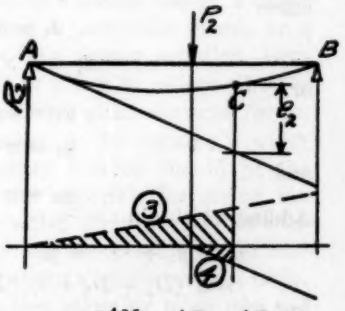
But

$$e_{1-k} = \Sigma_C^A M_{1-k}/EI. \tag{6}$$

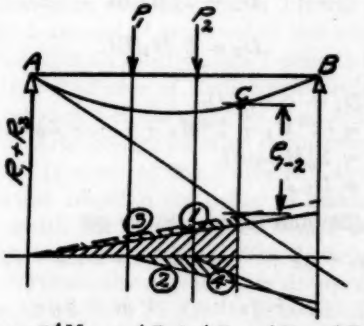
Remembering now, that the bending moment corresponding to k loads acting simultaneously is by definition the algebraic sum of the bending moments corresponding to the loads acting separately, it follows that the area-moment about any point in the case of simultaneous action equals the algebraic sum of the area-moments in the case of separate action, see Figs. 2, 3, 4.



$e_1 = \Sigma_C^A M_1 = A_1\bar{x}_1 - A_2\bar{x}_2$



$e_2 = \Sigma_C^A M_2 = A_3\bar{x}_3 - A_4\bar{x}_4$



$e_{1-2} = \Sigma_C^A M_{1-2} = A_1\bar{x}_1 + A_3\bar{x}_3 - A_2\bar{x}_2 - A_4\bar{x}_4$

FIGS. 2, 3, 4.

Hence

$$\Sigma_C^A M_{1-k} = \Sigma_C^A M_1 + \Sigma_C^A M_2 + \cdots + \Sigma_C^A M_{1-k}. \tag{7}$$

Substituting equation (7) in (6) we get

$$e_{1-k} = (\Sigma_C^A M_1 + \Sigma_C^A M_2 + \cdots + \Sigma_C^A M_k)/EI. \tag{8}$$

Consequently

$$e_{1-k} = e_1 + e_2 + \cdots e_k. \tag{9}$$ Q.E.D.

Now,

$$y_1 = d_1 - e_1, \tag{10}$$

$$y_2 = d_2 - e_2, \quad \text{etc.} \tag{11}$$

But from similar triangles

$$d_1/D_1 = AC/AB = a, \quad \text{a constant;} \tag{12}$$

hence

$$d_1 = a \times D_1, \tag{13}$$

$$d_2 = a \times D_2, \quad \text{etc.,} \tag{14}$$

or

$$y_1 = a \cdot D_1 - e_1, \tag{15}$$

$$y_2 = a \cdot D_2 - e_2, \tag{16}$$

and

$$y_k = a \cdot D_k - e_k. \tag{17}$$

Adding we obtain

$$y_1 + y_2 + \cdots + y_k = a \cdot (D_1 + D_2 + \cdots D_k) - (e_1 + e_2 + \cdots e_k), \tag{18}$$

but

$$D_1 = \Sigma_B^A M_1/EI \tag{19}$$

and

$$D_2 = \Sigma\ M_2/EI. \tag{20}$$

Hence

$$(D_1 + D_2 + \cdots + D_k) = (\Sigma^B M_1 + \Sigma^B M_2 + \cdots + \Sigma_B^A M_k)/EI \tag{21}$$

$$= \Sigma_B^A M_{1-k}/EI \tag{22}$$

$$= D_{1-k} \tag{23}$$

Substituting (23) and (9) in (18) we get

$$y_1 + y_2 + \cdots + y_k = a \cdot D_{1-k} - e_{1-k} \tag{24}$$

or

$$y_1 + y_2 + \cdots + y_k = y_{1-k} \tag{25}$$

which is the theorem we set out to prove. The same conclusion will hold for distributed loads since these may be looked upon as an infinite number of concentrated loads.

ENGINEERING EDUCATION AND THE SMALL UNIVERSITY

BY

BRUCE D. GREENSHIELDS

Professor of Engineering Science, Denison University, Granville, Ohio

Every year, in an increasing number, high school graduates with the help of their elders are deciding what college or university to attend. Various factors influence this decision such as a family tradition of attendance at a certain college, a desire to keep on with friends attending a particular school, or a consideration of relative costs. The proper selection, however, depends upon the purpose of going to college whether it is for pleasure, for forming desirable social contacts, for receiving training in some profession, or for gaining a wider general knowledge. The university selected should be the one best equipped in teachers and materials for giving the desired training—the university which offers the type of education designed to fit the student for his chosen work in life, or which will help him to decide wisely what his work is to be.

The question of whether a student planning to go into the engineering profession should attend a Liberal Arts College offering a limited amount of engineering was presented to me as a problem for solution shortly after I came to Denison University, as Acting Professor of Civil Engineering, in the fall of 1926. The other side of the question is, of course: Does it pay the Liberal Arts College to offer engineering work?

The Board of Trustees of the University about this time passed a resolution adopting the policy of making Denison a University in which the Liberal Arts should be stressed to the exclusion of vocational subjects. The Bachelor of Science, and Bachelor of Philosophy degrees were dropped so that now only the degree of Bachelor of Arts is granted. Denison University has offered a limited number of Engineering courses

under the head of Civil Engineering since 1885. The work was given by the Mathematics Department until 1904, when a separate department known as the Department of Civil Engineering was formed. The present plan, which is not much changed from that of past years, is to offer twenty-four to forty semester hours of Engineering as a major, granting the student an A.B. degree upon completion of the college course. As stated in the general catalog, the Department, which has now been changed to Department of Engineering Science so that its name may fit the work offered, aims to teach only basic courses; but owing to lack of laboratory facilities the curriculum has a civil engineering flavor. This change was recommended by W. E. Wickenden, Director of Investigation of the Society for the Promotion of Engineering Education, who says: "My understanding is that the trustees have announced the policy of limiting the scope of the institution definitely to that of a liberal college. There is no reason why a department and group of courses should not be included under some such title as Engineering Sciences, but it scarcely seems consistent with this policy to offer what purports to be a self-contained training in some one professional division of engineering. The engineering subjects to be offered under the title Engineering Sciences would be those of most general character and widest occurrence in engineering curricula and which afford the basis for specialized engineeering study rather than reach up into it."

The twenty-four hours required for a major must include Drawing, Surveying, Materials of Construction, Technical Mechanics and Mechanics of Materials, courses having a prerequisite of twenty hours of Mathematics and ten hours of Physics.

The courses offered in the Department at present are as follows:

Mechanical Drawing	4 hours
Machine Drawing	2 hours
Descriptive Geometry	4 hours
Elementary Surveying	4 hours
Technical Mechanics	4 hours

Mechanics of Materials	4 hours
Materials of Construction	4 hours
Highway Engineering	3 hours
Advanced Surveying	3 hours
Railroad Curves	3 hours
Hydraulics	3 hours
Analysis of Structures	4 hours
Structural Design	4 hours

As a matter of historical interest several catalogs were selected at random and the courses offered during the respective years are indicated:

1871–2

Surveying and Navigation
Roads and Railroads

1897

Surveying:
Land Surveying—Road Surveying—Railroad Surveying
Structures:
Ground Structures; Bridge Trusses, Strength of Materials

1904

1. Mechanical Drawing
2. Descriptive Geometry
3. Plane Surveying
4. Railroad Surveying and Earthwork
5. Topographical Surveying and Mapping
6. Sanitary Engineering
7. Analysis of Structures
8. Strength of Materials
9. Topographical Drawing
10. Highway Construction and Maintenance
11. Railroad Engineering
12. Applied Mechanics
13. Drafting
14. Water Supply and Irrigation Engineering
15. Details of Construction
16. Railroad Standards
17. Masonry Construction
18 and 19. Lettering
20 and 21. Technical Reading

Total Hours—59

1912

1–2. Mechanical Drawing
3. Descriptive Geometry
4. Plane Surveying
5. Railroad Surveying
6. Railroad Engineering
7–8. Applied Mechanics
9. Analysis of Structures
10. Roof and Bridge Design
11. Topographical Surveying or Mapping
12. Cement Testing
13. Highway Construction and Maintenance
14. Hydraulics

Total Hours—45

The conservative policy of keeping the scope of the work of the University within such bounds as will enable it to excel in the quality of its teaching is without question a wise one, for a school with its enrollment limited to one thousand students and its main activities directed elsewhere cannot maintain either the equipment or the teaching staff to offer an engineering curriculum comparable to those of the state universities or technical colleges. This does not, however, indicate, as it would seem to, that some engineering, which is a specialized, professional course, should not be retained in a liberal arts college, but it does mean that if any engineering courses are to be offered it must be for reasons aside from engineering itself. The engineering student can profit from attending a liberal arts college only if this type of college can give him something of value that he cannot get as well elsewhere.

If the engineer needs a certain amount of liberal education, it must be on account of certain characteristics of his for which he is being criticized, and which may be caused by some deficiency in his training, which a general education can supply. One of these is his reputation for narrowness, his inability to recognize and appreciate the other fellow's point of view. This may arise from the nature of his profession, but may also be due to his education. He is trained in a particular field by specialists who are very likely to attach undue importance to the subject they are teaching and who must, since they are specialists, know so much about one thing that they often have no time to know anything about much else.

Lack of ability to express himself in writing or speaking is another well-known shortcoming of the engineer. This is a serious defect for the engineer who deals with an exact type of work which demands accurate explanation. Specification writing calls for correctness and clarity. A mistake in English here may mean a loss of thousands of dollars.

The engineer is also often characterized as an unsociable being, and so it is felt that his training could be of more service to humanity if he were able to mix more agreeably with his associates.

The engineer can make use of liberal education just as much as any one else, for the highest positions in the field of business and industry that fall to the engineer demand a training that no one type of school can give. The technical college can teach him how to "use and direct the forces of nature for the benefit of mankind," but it does not always teach him how to understand, associate with, and direct his fellowmen, and this the engineer must do, for all important industry requires the united and directed work of many. In considering any problem of Engineering Education we can hardly disregard the work of the Society for the Promotion of Engineering Education which after an investigation conducted over three years in which approximately 140 schools and various other agencies cooperated, finds that the engineering graduate's greatest criticism of his course is that "the course offered no advancement in the appreciation of the finer and cultural things of life," and says that "while preliminary study in an arts college seems fairly certain to remain voluntary for prospective engineering students, it may well be encouraged more widely for the sake of its personal and cultural values.

"Likewise, a suitable program for recommendation to arts colleges in conjunction with reasonably preferential terms of admission to advanced standing in engineering, so that the combination might fill five well planned years, seems highly desirable to encourage greater recruitment of engineering students from this particularly preferable source," but a curriculum that does not contain elements of engineering is not recom-

mended as "it is more apt to turn students away from engineering than to encourage them in the field."

But, while the Society recognizes the need to develop, broaden and enrich engineering education, in view of the constantly enlarging responsibilities of engineers in society and the increasing exactions of professional practice, it states that there "appears to be little demand for a longer scholastic program for the average student."

The Committee on Engineering Education of the American Association of Engineers after considering the results of queries put to one thousand captains of industry resolved that: as a rule, Engineering courses are too narrow, and that students should study more of the "humanities," should learn to read and speak the English language, and take courses in Public Speaking, Economics, and Business.

To get a check on the value of the arts-engineering course given at Denison, a questionnaire was recently sent out to one hundred and seventy graduates in this course. (Owing to the fact that graduates are not listed according to majors, four replies were from men who did not major in Engineering at Denison. Two of these took engineering elsewhere.) A frank criticism was asked, for the purpose of the questionnaire was to find out whether a semi-technical course is really worth while. The ninety-four replies are from men in a wide range of occupations, sixty-two being engaged in engineering and the others in various professions, and contain information of value to any one interested in college education. As shown by the replies, sixty-three per cent of the graduates engaged in engineering took additional work at such schools as Cornell, Columbia, Massachusetts Institute of Technology, Ohio State University, Wisconsin University, etc., so that these men are well qualified to judge as to the relative value of training at a liberal arts college and at a technical school.

The answers to the questions show that the small university or college may play an important part in the training of engineers without, in any way, competing with the strictly technical school but rather by supplementing its work by pre-

liminary fundamental training. The intensive training of the technical school prepares the student in his chosen field much better than the smaller school can hope to do and if that is the only end sought, then the student should forego the longer curriculum of a combined course. Also even though the cost per year is often less at a smaller school, the extra year of study usually means extra cost in money as well as time.

The following advantages of a semi-technical program of studies seem pretty well established:

1. The student spends the early formative years of his college life in the desirable, cultural, social and moral atmosphere of a small first class arts college.

2. The abrupt change between the work in the average high school and work of the technical school is avoided and the student who enters college at a younger age than formerly, has an opportunity to develop the proper habits of study and gain the fundamentals under less pressure than he would at a technical college.

3. The student with an inclination towards engineering has an opportunity to defer the answer to that most important question of his life: "Do I want to become an engineer and am I fitted to be one?" till greater knowledge of what the profession of engineering means and maturer years make the answer more certain of being a correct one.

4. Such a semi-technical program enables the student upon graduation to find profitable employment in the engineering field, deferring the taking of complementary work in engineering until circumstances and opportunity have pointed out for him the most desirable branch of engineering to follow.

5. The favored student has an opportunity to plan a well balanced five year program giving desired cultural training in a first class arts college and technical training in an engineering school, with no lost time such as would occur if the arts curriculum were not semi-technical.

6. The student who does not intend to be an engineer has the opportunity of taking courses in engineering for their general educational value, receiving credit for the A.B. degree. Experience has shown that engineering methods can be applied

with profit in the pursuit of many non-engineering professions.

The following constitute the questions and respective answers:

NUMBER 1: *Is there any advantage in an engineer's taking work at a liberal arts college?*

Eighty-seven per cent of those answering this question advise a liberal arts course for engineers. Most engineers favor the extended program of five or six years as it gives the student a chance to have the broadening influence of the liberal arts college and the time to make up his deficiency in English, Economics, Business, and the "humanities" in general. Many students entering college are not decided on what profession to follow and these can be helped to a wise decision by a general course of study.

Of the following comments five are from men who have taken additional work in Engineering: three at Massachusetts Institute of Technology, one at Cornell, and one at Wisconsin.

"I think that there is no engineer who would not profit by taking work at a liberal arts college before he takes up his technical training. The liberal arts college is the most effective agency we have for developing breadth of view and broad cultural interests. The aim of the technical school, on the other hand, is specialization and a necessarily narrowing point of view. It is my personal opinion that to have the cultural work first enhances the student's appreciation of the technical studies. It has developed his judgment to see the technical work in its proper perspective."

—Production Engineer.

"I believe the smaller liberal arts colleges make a mistake in attempting to give a complete course in any branch of engineering. As a rule, they lack the equipment, the staff, and the close contact with practical construction and research problems which are found in the technical schools."

—Draftsman.

"I believe modern social and industrial conditions make the five or six year professional course well worthwhile and a decided advantage to the man who takes it. The liberal arts colleges can help by giving a thorough groundwork in Mathematics, Physics, Chemistry, English, and Economics, perhaps in a sort of 'pre-engineering' course, in addition to as much language, history and political science as time permits."

—Construction Engineer.

"I am inclined to believe that if Denison is made a purely liberal arts college, it will be a mistake. That is, if the courses in engineering are cut down or eliminated. I am quite sure that I would not have attended Denison if it had been only a liberal arts college. I could not have afforded to do so and I am sure there are many others of the same mind. Two or three years' work in a liberal arts college followed by three or four years in an engineering school is, in my opinion, an ideal way to secure an engineering training, but this is not always possible or convenient." —Purchasing Agent.

"I think an engineer should take a liberal arts course first and then continue in a technical school since the latter does not give enough time to the cultural side and turns out machines rather than broad-minded Christian citizens. I am quite certain that the stand taken by the Board of Trustees of Denison with regard to making it a liberal arts college is thoroughly sound. I am quite satisfied that Denison possesses neither the equipment nor the personnel facilities for adequate instruction in modern engineering; that her so-called engineering graduates are sure to find themselves strictly up against it in competition with graduates of our American technical schools. The atmosphere and attitude in our liberal arts colleges is entirely different from that found in our engineering schools and in my opinion engineering has no place in a school of the type of Denison. Her province lies in a direction other than the professional training of engineers." —Teacher.

"I have been a student at Denison and a student of a strictly technical school. The curriculum and the social and religious environments of the technical school are such as to narrow one's outlook on life's field of activity."
—Structural Engineer.

"I think it should be the mission of the smaller universities and colleges to guide the student who matriculates to the end that he can choose his life's work or profession. It need not offer highly specialized courses for they can be obtained in the professional schools. Very frequently, the freshman and sophomore student does not know what line of endeavor to follow and it becomes then the role of the college to offer him a varied curriculum from which he may choose to become a teacher, minister, doctor, lawyer, or engineer."
—Sanitary Engineer.

"By all means, build up the scientific departments at Denison, so that 'Hobson's Choice' need not be resorted to as in my case." —Manufacturer, Class, '71.

Some would not recommend more than a four year curriculum for the average student, owing to its cost in time and money.

"After finishing at Denison, to be on an equal with technical graduates, one has then to go to a technical school and fall in a year or two years behind his class and take the rest of the work that is not given at Denison. I think that not many high school graduates who are planning to take engineering courses will face that extra year or two very eagerly."

—Manager of a Coal Company.

NUMBER 2: *Should a student take work at a liberal arts college before or after his attendance at a technical school?*

Eighty-eight per cent advise the general course before the technical one, the expressed opinion being that the student will not be inclined to study the arts courses after he is prepared to go into the engineering profession.

NUMBER 3: *Did you find that you needed additional work in engineering to what you got at Denison?*

Eighty-nine per cent of these engaged in engineering find that they needed additional work.

In view of the incompleteness of the engineering curriculum at Denison this is what we should expect. In fact, it is surprising that eleven per cent found that they did not need additional work.

"The employer today is not looking for a thoroughly technical trained student for the fields have so many different phases that a specialization is almost impossible. The engineering profession from an employer's point of view is looking for the fellow who can best adapt himself to the conditions immediately at hand."

"It is much better for an engineer to know something of the meaning of Ethics and to have a good general knowledge of Railway Curves than to have no idea of what the word 'ethics' entails, combined with a specific knowledge of 'note forms,' 'special cases,' and 'text dogmas' which are nothing more than 'Brain crammers' and not 'brain developers.' An engineer is a man of broad knowledge, his specialization coming through the natural course of his experience."

—Assistant City Engineer.

"I am judging from my own experience when I say that a graduate from a co-operative school, such as the University of

Cincinnati, is two years farther advanced when he leaves school than is the graduate of a liberal arts college. The 'Co-op' student has come in contact with industry and knows its methods and its problems."

—Chemist in charge of Chemical and Testing Laboratories.

NUMBER 4: *What do you consider most lacking in the average engineering curriculum?*

Thirty-one per cent think there is not enough practical experience in the average engineering course. The "Cooperative" plan is advocated.

Fifteen per cent would recommend more economics.

Eight per cent say engineering students lack English.

Eight per cent think there should be more training in public speaking.

Thirty-six per cent mention various other subjects such as mathematics, fundamentals, arts subjects, etc.

The following replies are typical:

"Economics, Public Speaking, English, General Education, are the subjects most lacking in the average Civil Engineering Curriculum."—Sales Engineer.

"Too much specialization of courses. Insufficient emphasis of fundamentals."—Research Chemist.

"My experience with graduate engineers has been that they do not lack the advantages that further study of the general arts would have given them so much as they lack an understanding of the application of their technical education to the practical problems with which they are confronted. Of course, the more extended their arts studies are the broader and more versatile they become under any circumstances, but to the point, the essential knowledge missing in most graduate engineers is 'finance and economics.' Engineering must not be ethereal, but have its feet on the ground. Squeezed in as it is with the balance of the business world it must have an understanding of business methods and conditions. It is not difficult technically to design a bridge, a building, a railroad, a sewerage, or a water plant; but to design so that they meet the economical demand of the situation requires a knowledge of the conditions that others will have to contend with in making the project a reality. The course should include: Government, Law, Taxes, Public Officials, Banks and Finance, Promotion and Publicity, Bonds, Interest, Sinking Funds, etc."
—Consulting Sanitary Engineer.

NUMBER 5: *Is Denison's semi-technical curriculum a good one for engineers?*

Eighty-seven per cent of those answering this question think it is good.

"If I knew that it was necessary for me to get to work as early as possible, I would certainly choose a good technical school and one that was in a position to furnish the greatest possible amount of practical engineering. If the money was available and I felt that I could spend a little more time in my education, then I think a school of a semi-technical curriculum like Denison with two years at a good technical school would be my choice."—Construction Engineer.

"Studying engineering in a liberal arts college enables one to work without pressure and thus get a solid foundation. In the engineering schools the student studies the details of the daily assignments without obtaining a general idea of what it is all about. The sudden change from high school to the high pressure work of a good engineering school is too sudden for the average student."—Commercial Worker.

"The Department of Civil Engineering at Denison University has met the wants of former students at Denison and apparently from the recognition given to these men in the fields of engineering all over the world, the principles of engineering were most successfully taught. I grant you that there are a greater number of art students graduated from Denison University and in the public view than those of the engineering or scientific departments, but I very much question whether they have done as much in public affairs or brought as much recognition to Denison University as the latter."—Consulting Engineer.

NUMBER 6: *As a training for life what relative importance do you attach to the classroom work and to outside activities?*

Fifty-four per cent rate classroom work and outside activities of equal importance.

Twenty-four per cent think classroom activities come first.

Twelve per cent consider outside activities of more importance.

Ten per cent give various proportionate ratings.

General school activities are regarded as highly important. Training in the ability to understand and get along with one's fellowmen is thought quite as necessary as technical training,

as the highest positions in business demand character as much as ability. It is largely in activities outside of the classroom that the desirable atmosphere of a small college plays its part in education.

NUMBER 7: *In the light of your practical experience, how would you now plan your education; what type of school and courses of study?*

Sixty-eight per cent would combine more or less arts courses with their engineering.

Six per cent favor the co-operative plan.

Six per cent would take combined business courses with engineering.

Nineteen per cent favor the strictly technical course.

Fifty-five per cent of those not engaged in engineering who answered this question would take a general arts course and then technical work.

"I would take a six year course; two years general education and four technical."—Civil Engineer.

"I would study at a liberal arts college until ready for technical training."—Chief Engineer.

"Degree from Denison, then technical school with plant experience during vacations."—Department Head, Chemical Laboratory.

"Four years at Denison, two years practical experience, then good technical school."—Assistant Engineer.

NUMBER 8: *If you are not engaged in engineering do you find your training in engineering of any benefit in the work you are now following?*

Ninety-four per cent answer in the affrmative.

The training of the engineer consists in learning not only facts but how to use these facts in the solution of problems. Herbert Hoover is cited as a man who is very successfully applying the engineering method to problems of industry, business and commerce.

"Yes, absolutely. It has taught me to analyze all problems and in my insurance business has been of great help in rate-making and fire prevention engineering."—Insurance Counselor.

"Yes. It enables me to arrive more quickly at concise and

definite conclusions and to handle technical matters, such as my work involves, with greater ease."—Manager Retail Lumber Yard.

"It is a benefit. My study in engineering taught me how to attack and solve problems. I find that this is helping me a great deal in the studying of medicine."—Student.

"Engineering training is an excellent background for systematic thinking and accurate execution. I consider that I took the proper training for my work."—Vice-President and Trust Officer of Bank.

A LETTER TO THE PRESIDENT

WESTERN ELECTRIC COMPANY
INCORPORATED
195 BROADWAY
NEW YORK

F. W. WILLARD
PERSONNELL DIRECTOR

March 21, 1929

DEAN DEXTER S. KIMBALL, President,
Society for the Promotion of Engineering Education,
Cornell University,
Ithaca, New York.

Dear Dean Kimball: I thank you for your gracious letter of March 18th. It is our policy to support, to the extent of our ability, those agencies which seem to us to be doing the best constructive work directed toward the better training of young men in the higher institutions. We have felt for some time that the Society for the Promotion of Engineering Education is one of the best of these instrumentalities.

We do not consider that the contributing of money toward the expenses of the Purdue Summer School is in and of itself the most important part of our assistance, in that such support, essential as it is to the success of the undertaking, involves on our part little personal and individual effort. To us the participation by some of our executive and administrative officers in the actual program of the School is the important part of our share. It is to this that we are directing our best effort. We are confident that we are going to get more out of it than we are able to give.

Those of us who are designated to participate in this program are not teachers by experience or by talent. Participating in this school, along with some of the best teaching talent in the country, we hope to learn something about the problem of training young men, and by that learning to be better able to assist the engineering faculties in the future.

Yours sincerely,

F. W. WILLARD.

COLLEGE NOTES

The Juniors and Seniors of **Case School of Applied Science** have voted to have readings in plays for their elective English course. It is interesting to note that all the students are taking engineering and are not usually supposed to be interested in such forms of literature.

The class has read four of Shakespeare's plays and is now reading Ibsen and Oscar Wilde. The course will include European and American plays, both old and modern. The members of the class have been assigned parts in the plays to make the readings more interesting.

Action to create such an elective course came directly from the students. Their interest in cultural subjects is another indication of the steady growth of engineering education toward breadth of training.

University of Illinois.—A number of changes have taken place in the faculty of which the following may be mentioned: Messers. E. F. Wilsey and W. E. Smith of the department of Theoretical and Applied Mechanics resigned to teach engineering at Robert College, Constantinople.

A number of the faculty have been in foreign countries during the past year for study and travel. Assistant Professor J. T. Tykociner in Electrical Engineering has returned from a sabbatical leave which he spent in Europe visiting laboratories and studying new methods of research.

Professor H. E. Babbitt in Sanitary Engineering spent the summer in Central America and Colombia studying sanitary conditions in those places.

Dean Milo S. Ketchum spent the summer in Europe. He visited the leading universities and research laboratories in England and on the Continent.

Professor Rexford Newcomb of Architecture has a leave of absence for six months which he is spending in Japan. He will make a study of Japanese architecture and will attend the Engineering Congress at Tokyo.

The College of Engineering is adding a new building to its group, a Materials Testing Laboratory. It is in process of construction and it is expected that it will be ready for occupancy some time during the summer. It will contain the offices and laboratories of Theoretical and Applied Mechanics and the laboratories of Civil Engineering. The gathering together of these two departments will allow the needed expansion of other departments, especially those of Electrical Engineering and Ceramic Engineering.

The building is I-shaped in plan and four stories high. The end wings will contain the student laboratories and the small research laboratories and the connecting stem will contain offices and a testing bay for handling large, heavy work. Among the new machinery which will be installed in the laboratory is a 3,000,000 pound testing machine which will take a tensile test specimen 40 feet long. This will be erected during the summer and fall. This large machine will permit the conduct of some large-scale tests which have hitherto not been possible here.

The research program of the Engineering Experiment Station continues to be large. Numerous large projects, such as a study of warm-air heating furnaces, stresses in railroad track, and fatigue of metals, which have been in progress for many years are being carried on actively. In addition to these, three new projects of considerable importance have been begun, viz., investigation of cast-iron pipe, a study of riveted joints, and transverse fissures in rails. The engineer of tests for the latter project is Special Research Associate Professor H. R. Thomas from the University of Texas.

INCREASE THE MEMBERSHIP

You can assist the Membership Committee in increasing the membership of the Society by having one of your colleagues, who is not a member and who should be, fill out this application blank, and return it to the secretary, F. L. Bishop, University of Pittsburgh, Pittsburgh, Pa. All applications received before June 15 will be acted upon by the Society at its meeting in Columbus, June 19–21, 1929. The dues are five dollars per year. Secure at least one new member before the year closes!

Return to the Secretary, F. L. Bishop, University of Pittsburgh, Pittsburgh, Pa.

SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION

Date .....

THE UNDERSIGNED desiring to become a member of

THE SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION

hereby agrees to conform to the requirements of membership, if elected, and submits the following:

STATEMENT OF QUALIFICATIONS

Full Christian Name and Surname .....
PRINT LAST NAME FIRST MIDDLE

Mailing Address (Number and Street) .....

Post Office (City and State) .....

Full Title of Professional Position .....
(TITLE) (DEPARTMENT)

Full Name of Institution .....

(To be Signed by Two Sponsors)

SPONSORS .....
.....

YOUR SOCIETY BUDGET

At the beginning of each year, the Society prepares a budget on the basis of dues from the number of members on the roll at that time, and expenditures are made accordingly. Three notices have been sent but some of the members have not paid their dues and, as a consequence, when bills are received for expenditures incurred, we cannot pay them promptly.

The dues are only $5.00 per year. If you have not paid your 1928–29 dues, please send your check at once to the secretary, F. L. Bishop, University of Pittsburgh, Pittsburgh, Pa. If you are not sure whether or not you have paid your dues, send your check for $5.00. If your dues for 1928–29 are not paid, the check will be credited to that account. If your 1928–29 dues are paid, your check will be credited to your 1929–30 dues and a receipt will be mailed to you.

NEW MEMBERS

ABBOTT, THOMAS A., Instructor in Electrical Engineering, Yale University, New Haven, Conn. Chas. F. Scott, R. G. Warner.

ALLISON, WILLIAM H., Instructor in Civil Engineering, Yale University, New Haven, Conn. C. T. Bishop, C. S. Farnham.

BERRY, C. HAROLD, Professor of Mechanical Engineering, Harvard University, Cambridge, Mass. H. J. Hughes, L. S. Marks.

BRODHEAD, JOHN A., Director, New Haven College, New Haven, Conn. Chas. F. Scott, R. G. Warner.

CARTER, CLINTON C., Professor of Natural and Experimental Philosophy, U. S. Military Academy, West Point, N. Y. D. C. Jackson, F. L. Bishop.

CHATELAIN, MIKAEL, Professor of Electrical Engineering, Polytechnic Institute, Leningrad, Russia. W. E. Wickenden, R. H. Spahr.

DAVIS, HOWARD L., Director of Technical Employment and Training, New York Telephone Co., 140 West Street, New York City. R. I. Rees, O. W. Eshbach.

ECKLE, JOHN N., Assistant Professor of Engineering Drawing, Yale University, New Haven, Conn. R. S. Kirby, Chas. F. Scott.

FINDLEY, WARREN G., Assistant in Psychology, Cooper Union, New York City. W. J. Pickett, Geo. F. Bateman.

FRY, THORNTON C., Member, Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York City. John Mills, H. S. Sheppard.

GOUNARIDES, ALEXANDER, Instructor in Electrical Engineering, Yale University, New Haven, Conn. Chas. F. Scott, R. G. Warner.

JAMIESON, ROBERT E., Assistant Professor of Civil Engineering, McGill University, Montreal, Canada. H. M. MacKay, C. M. McKergow.

MCBRIDE, WILBERT G., Professor of Mining Engineering, McGill University, Montreal, Canada. H. M. MacKay, C. M. McKergow.

NEWMAN, ALBERT B., Professor in charge of Department of Chemical Engineering, Cooper Union, New York City. G. F. Bateman, F. L. Bishop.

PRATT, CHARLES, Secretary, Board of Trustees, Pratt Institute, Brooklyn, N. Y. S. S. Edmands, A. L. Cook.

WINGREN, ROY M., Instructor in Mechanical Engineering, Texas A. & M. College, College Station, Texas. F. C. Bolton, Ray Flagg.

WINSTON, STANTON E., Associate Professor of Kinematics, Armour Institute of Technology, Chicago, Ill. C. I. Palmer, J. C. Penn.